Paying for Green: Tax credit and Solar Adoption

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Abstract

We develop a dynamic discrete–continuous choice model of household portfolio decisions and residential solar adoption within a heterogeneous-agent framework. First, we characterize the novel interaction among liquid assets, mortgage debt, and solar adoption. Second, we use the model to evaluate the impact of federal tax credits on solar adoption. Our findings indicate that the current 5% aggregate adoption rate is largely driven by these tax credits. We show that a universal preference shift, valued on average at 5% of installation costs, can replicate the aggregate adoption effect of these credits in their absence. However, the distributional effects of these two approaches differ significantly: tax credits are essential for overcoming liquidity constraints among lower-income households, whereas preference-based interventions are particularly effective at mobilizing wealthier households that currently forgo installation due to non-pecuniary barriers.

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Keywords: Residential solar adoption, tax credit, dynamic discrete choice, heterogeneous-agent model, non-pecuniary incentives, renewable energy diffusion.

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1 Introduction

U.S. distributed solar installation history, as summarized in Tracking the Sun 2024, shows a long-run market expansion paired with lower real prices. According to the data, distributed solar installations reached an estimated 4.74 million cumulative systems nationwide through 2023, with roughly 775,000 systems installed in 2023 alone.

This rapid increase is closely related to federal tax credit policy (Hughes and Podolefsky, 2015). The residential energy tax credit originated with the Energy Tax Act of 1978, which established a 30% tax credit. Following the end of the 1970s energy crisis, the credit expired but was later reinstated by the Energy Policy Act of 2005. While subsequent legislative extensions were intended to sustain the incentive through 2035, the One Big Beautiful Bill (OBBB)—signed into law on July 4, 2025—abruptly altered this trajectory. The OBBB mandated the termination of the Section 25D Residential Clean Energy Credit on December 31, 2025. Consequently, as of 2026, direct-purchase residential solar credits are no longer available to U.S. homeowners.

Under these circumstances, it is important to understand to what extent the current 5% adoption rate (American Housing Survey) is attributable to the federal tax credit and what would happen if the tax credit were removed. If the tax credit is indeed critical, an additional question is which alternative policies could promote solar installation in its absence.

In order to answer these questions, we build a heterogeneous agent macroeconomic model featuring dynamic continous-discrete choices regarding housing, liquid asset, mortgage debt, and solar adoption. Furthermore, we introduce an exogenous non-pecuniary parameter that can be interpreted as pro-social 'warm-glow' motivation or, conversely, a psychological hurdle to explain the residual that the model otherwise leaves unexplained.

In the baseline model with a 30% federal tax credit, we calibrate the solar installation rate and other key housing market moments to match the data. We find that the probability of solar installation follows a hump-shaped distribution relative to liquid assets across all housing sizes. Furthermore, this probability increases with the unit price of electricity. Interestingly, this hump shape is largely explained by remaining mortgage debt. Households with higher mortgage debt exhibit a more pronounced hump-shaped pattern. Under our assumption of an exogenous solar home premium, more highly indebted households are more likely to adopt solar because

the associated capital gain increases their home equity. Regarding distributional outcomes, as expected, the majority of solar installations are performed by households with above-median income; specifically, 73% of installations are accounted for by this group.

We conducted two counterfactual experiments. First, we removed the tax credit and solved for the new steady state. Second, we removed the tax credit while increasing the non-pecuniary parameter to achieve the same aggregate solar installation rate as the baseline—a scenario we term 'Universal Preference Change.' This allows for a comparison of the long-run effects of policy versus preference shifts. In the first experiment, we find that a 0% tax credit effectively wipes out the solar market, with only 1/30th of the original installations remaining. This is a more dramatic result than the empirical evidence from Hughes and Podolefsky (2015), which attributes 50% of solar adoption to tax credits; however, as we are comparing two distinct long-run steady states, this discrepancy is expected.

The core of our research is our third experiment, where we engineer a scenario to generate the same aggregate installation rate as the baseline. We find that the peak of the hump-shaped probability curve is lower, but the right tail is significantly fatter, indicating that removing the tax credit and increasing the common preference has a non-linear effect on asset distribution. While the preference shift fails to compensate for the financial constraints faced by poorer households, wealthier households are more likely to adopt solar panels compared to the baseline. This occurs because their previous non-adoption was driven by preferences rather than financial hurdles. Consequently, we find that more than 86% of solar installations are attributed to households with above-median income.

Finally, we calculate the willingness-to-pay equivalent of this parameter to determine what is needed to achieve. Our calculated willingness-to-pay (WTP) for this parameter is approximately 5% of the total installation cost. This is a reasonable estimate, as Bollinger et al. (2026) estimate the signaling effect to be in the range of 1.2%. This suggests that the alternative non-monetary policy intervention proposed in our model is well-aligned with observed empirical evidence and is a plausible mechanism for achieving aggregate adoption goals.

The remainder of this paper is organized as follows. Section 2 reviews the related literature, and Section 3 provides a detailed description of the model. In Section 4, we outline the calibration

strategy. Section 5 presents the results of the baseline model. Section 6 discusses the counterfactual analysis regarding tax credits and preference changes. Finally, Section 7 offers concluding remarks.

2 Literature review

This paper contributes to a growing body of literature that examines subsidy design for the diffusion of renewable energy technologies (Doulos et al., 2019; Couture and Gagnon, 2010; Klein et al., 2008; Menanteau et al., 2003; Butler and Neuhoff, 2008; Bento, 2013). A specific strand of this research focuses on residential solar energy policy. One group of studies employs empirical analysis to evaluate the effect of subsidies on solar installation rates. For instance, Hughes and Podolefsky (2015) estimate that 53% of residential solar installations in California are attributable to upfront subsidies provided by the California Solar Initiative. Borenstein (2017) extend this analysis by examining the interaction between tiered tariff structures and federal tax credits.

Alternatively, another strand of research utilizes a structural approach by developing and estimating dynamic discrete-choice models of residential solar adoption (De Groote and Verboven, 2019; Burr, 2014; Feger et al., 2022; Langer and Lemoine, 2022). Specifically, Langer and Lemoine (2022) analyze time-varying subsidies in the context of declining installation costs and fluctuating electricity prices. Their model demonstrates that an increasing subsidy schedule is efficient, as it achieves an allocation of smaller subsidies to households with a higher willingness to pay through price discrimination. Feger et al. (2022) broaden this discussion by providing a comprehensive analysis of the interplay between the structure of electricity two-part tariffs and solar installation subsidies. In contrast to the aforementioned structural estimation studies, we develop a heterogeneous agent model—in the spirit of Aiyagari (1994)—that incorporates a dynamic discrete-choice framework. Our model captures realistic housing, mortgage, and solar adoption choices under stochastic electricity prices. By doing so, we can clearly evaluate how solar subsidies influence household decision-making. Incorporating housing and mortgage choices is critical, as homeownership is a necessary condition for solar adoption—a factor largely overlooked in previous research.

In contrast to the price-oriented environmental policy mechanisms discussed in the aforementioned literature, changes in consumer preferences represent another significant dimension, as highlighted by Stern (2008). Stern points out that pro-social behaviors, such as recycling or

cautious driving, are driven not only by financial incentives but also by a sense of civic responsibility. Specifically, a substantial body of literature examines the non-economic motivations behind pro-social behavior, a subject well-reviewed in Bollinger and Gillingham (2012). Bollinger and Gillingham (2012) estimate peer effects in solar adoption by analyzing how the current density of solar installations affects the probability of new installations using zip-code-level microdata. In a similar context, Bollinger et al. (2026) examine how willingness-to-pay (WTP) is rooted in self-image and social signaling. They demonstrate that the interaction between the political composition of a neighborhood and the individual adopter's political alignment jointly affects their WTP for solar adoption by through self and social signaling path.

Another psychological dimension of solar adoption concerns the behavioral barriers to installation. Research in this area explores why homeowners may resist adoption despite economic incentives[1]. Kunreuther et al. (2022) and De Groote and Verboven (2016) note that cognitive biases—particularly present bias or short-sightedness regarding new technologies—cause consumers to postpone the adoption of residential solar systems, even when doing so offers clear financial advantages. While most studies examining the psychological benefits or barriers of new technology adoption—such as peer effects, signaling, and cognitive hurdles—typically employ empirical strategies, this research utilizes a reverse-engineering approach using structural model. We re-calibrate the underlying parameters governing exogenous solar preferences to assess how a universal shift in preferences differs from price-based subsidies in terms of both distributional and aggregate impacts.

[1]There is a conflict regarding the economics of solar panels. Some researchers argue that residential solar systems are not cost-effective, as their installation costs often exceed the value of the electricity they produce. For instance, Borenstein (2008) estimates that solar photovoltaic systems cost approximately 80% more than the market value of the electricity they generate. Similarly, Dastrup et al. (2012) suggests that these systems lack economic viability when evaluated solely on energy efficiency. Furthermore, Borenstein (2012) finds that even when accounting for environmental externalities, residential solar systems remain less cost-effective than traditional gas-fired generation. In contrast, other scholars contest this view. Eid et al. (2014) highlights that residential solar can be economically advantageous when integrated with net metering policies, which allow households to offset electricity costs more effectively.

3 Model

3.1 Overview

We extend the discrete-choice models of solar adoption developed by (Burr, 2014; De Groote and Verboven, 2019; Feger et al., 2022) to a heterogeneous-agent macroeconomic setting. Our framework captures a realistic adoption process. Because renters rarely install solar panels, homeownership is typically a necessary condition for adoption. Accordingly, we enrich the solar adoption model by introducing housing tenure choice, mortgage borrowing, and idiosyncratic income risk. Additionally, the model includes an idiosyncratic electricity price shock, which allows us to examine how differences in electricity prices affect solar adoption decisions.

In the model, households first choose their housing tenure and borrowing position. Conditional on owning a regular home, they may subsequently install solar panels, which constitutes the main pathway into solar homeownership. We also allow renters to directly purchase a house with solar panels already installed. Both a tax credit for solar installation and an exogenous non-pecuniary preference shifter play important roles in the solar adoption process.

3.2 Households

3.2.1 Household Environment

Demographic A continuum of infinitely-lived households exist in economy. Time is discrete denoted by t.

Preference

$$U^i(c_t, e_t, s_t) = \frac{\left\{ \left[\phi_c^{\frac{1}{\epsilon}} c_t^{\frac{\epsilon-1}{\epsilon}} + \phi_e^{\frac{1}{\epsilon}} e_t^{\frac{\epsilon-1}{\epsilon}} + \phi_s^{\frac{1}{\epsilon}} s_t^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{1}{1-\epsilon}} \right\}^{1-\frac{1}{\gamma}}}{1-\gamma} \tag{1}$$

The period utility is CRRA over a CES composite of consumption c_t, net electricity e_t, and housing services s_t, where ϕ_c, ϕ_e, ϕ_s are preference weights, ϵ governs the elasticity of substitution across goods, and γ controls risk aversion. β is time discount rate. In addition to the baseline preferences, we introduce a preference shock to smooth the probabilities of discrete choices and to capture non-pecuniary preferences for solar installation, as discussed in Section 3.2.2.

Endowment Income for household i at time t are composed of three parts: the aggregate income level Z_t, a persistent component η_t, and a transitory component θ_t, as shown in Equation 2.

$$y_t^i = w_t \cdot \exp\left(\theta_t^i + \eta_t^i\right) \tag{2}$$

Here, η_t is the persistent component of income and follows an AR(1) process, as given in Equation 3, where ρ is the AR(1) coefficient and ϵ_t is white noise following a normal distribution with mean zero and variance $\sigma\epsilon^2$.

$$\eta_t = \rho\eta_{t-1} + \epsilon_t \text{ with } \epsilon_t \sim N(0, \sigma\epsilon^2). \tag{3}$$

The transitory income shock, θ_t^i, is assumed to follow normal distribution with mean zero and variance σ_θ^2:

$$\theta_t^i \sim \mathcal{N}(0, \sigma_\theta^2). \tag{4}$$

Housing Households choose among three housing statuses: renting, owning a regular home (without solar panels), or owning a solar-equipped home. Solar homes can generate electricity, and generation capacity depends on the size of the solar panel, which in turn depends on the size of the dwelling. We describe the electricity-generation technology in a later section. Electricity is non-storable. We assume it is tradable, but can't affect aggregate electric price.

In addition, regular homeowners may install solar panels at a later date. We describe the installation decision and its timing in section 3.2.2.

Owner-occupiers choose next period's housing stock h_{t+1} from the discrete set $\{h_1, \ldots, h_{n_h}\}$ at the unit price p_t^h. Housing depreciates at rate δ, implying a per-period maintenance (management) cost of δp_t^h per unit of housing. For homeowners (both regular and solar), the occupied housing stock maps one-for-one into housing services, i.e., $s_t = h_{t+1}$, which enters the utility function. Renters instead pay the rental rate p_t^r per unit of housing services s_t. We assume renters can choose housing services up from a set $\{s_1, ..., s_{n_r}\}$ where $s_{n_r} \leq h_1$ at all n_r. The rental rate is assumed to be an exogenous fraction of the house price, $p_t^r = \xi p_T^h$. Finally, there is an exogenous premium α^S for solar installed house, so that the unit price of a solar home is given by $p_t^s = p_t^h + \alpha^S$.

Mortgage and saving We assume a unified competitive mortgage market for both regular and solar homes. Households can originate a mortgage loan, m_{t+1}, to finance housing purchases. Mortgage borrowing is subject to an exogenous interest rate, r_t^m, and a fixed minimum repayment requirement. In particular, households must satisfy two constraints: a loan-to-value (LTV) constraint and a debt-to-income (DTI) constraint.

Let λ^l denote the minimum down-payment rate. Equation 5 represents the loan-to-value constraint as a function of house size and the house price:

$$-m_{t+1} \leq (1-\delta)\, p_t^h\, h_{t+1}\, (1-\lambda^l) \tag{5}$$

The DTI constraint imposes a minimum repayment (amortization) rate, ψ and debt to income ratio λ^π. Specifically, the minimum payment implied by ψ for a given loan amount must be lower than a fraction of income, as shown in Equation (6):

$$\psi m_{t+1} \leq \lambda^\pi y_t^i \tag{6}$$

We model long-term mortgage borrowing such that the mortgage repayment process follows Equation (7):

$$\pi_t^m \equiv m_{t+1} - (1+r_t^m) m_t \;\geq\; \pi^{\min} \equiv \psi\, m \tag{7}$$

We denote risk free saving, b_t with a exogenous price, r_t^b.

Electricity price process We assume that the electricity price is subject to an idiosyncratic shock. Thus, the unit electricity price, $p_t^{e,i}$, consists of an aggregate component, Z_t^e, and an idiosyncratic component, $\zeta_t^{e,i}$:

$$p_t^{e,i} = Z_t^e \exp\left(\zeta_t^{e,i}\right) \tag{8}$$

The idiosyncratic component follows the process in Equation (9):

$$\zeta_t^{e,i} = \rho_e \zeta_{t-1}^{e,i} + \epsilon_t^i \tag{9}$$

where $\epsilon_t^i \sim \mathcal{N}(0, \sigma_e^2)$.

Solar panel Owners of regular houses can install solar panels. The unit price of solar panels is p_t^p, so the total installation cost for a house of size h_t is $p_t^p h_t$. Electricity is produced according to the production function $F^e(h_t) = Qh_t$, which is linear in house size. Once a solar panel is installed, its value is capitalized into the house, increasing the unit house price from p_t^h to $p_t^s = p_t^h + \alpha^s$. The depreciation rate δ is applied to the total housing value, $p_t^s h_t$, implying that additional maintenance costs are incurred to maintain the solar panel.

Subsidy for solar panel A non-refundable federal tax credit is implemented. The effective tax, χ_t for solar installer is calculated by (10) where C is tax credit ratio.

$$\chi_t = \max\{0, \tau_y y_t^i - \mathcal{C} p^p h_t\} \tag{10}$$

Thus, effective net income for solar installer is $y_t^i - \chi_t$.

3.2.2 Household Decisions

In this section, we turn to recursive version of household problem with solar adoption. The household's decision process consists of three stages.

First, households without a home (n) choose between becoming a renter ($rent$), a new owner of a regular home ($f-owner-regular$), or a new owner of a solar home ($f-owner-solar$). A new owner can obtain a mortgage by satisfying two constraints: the loan-to-value (LTV) ratio and the debt-to-income (DTI) ratio. In addition, there is an exogenous preference shock across these options, $u = u^{rent}, u^{f-own}, u^{f-own-solar}$ drawn from an i.i.d. Type-I extreme value distribution, with the scale parameter in this step denoted by Λ^r.

Second, as homeowners ($owner-regular$), households can choose to either sell their home ($sell$), continue to repay their mortgage ($repay$), or install a solar panel ($install$) on their housing asset. This choice is influenced by an i.i.d. preference shock drawn from a Type-I extreme value distribution, with the scale parameter denoted by Λ^o. We also introduce an additive utility shifter, ω, for solar installation. If $\omega < 0$, it captures a non-pecuniary hurdle to installing solar panels; if

$\omega > 0$, it represents a non-pecuniary incentive to adopt them.

Third, homeowners with solar panels (*owner-solar*) can choose either to remain in the house and continue repaying the mortgage (*repay*) or to sell the house (*sell*). Same preference shock is introdunced here with scale paramter Λ^s

We have seven state variables here: risk-free asset a, mortgage debt m, persistent income shock η, temporary income shock θ, housing asset h, state of electiricity price p^e, and solar panel adoption $\aleph$. If household have a home with solar panel, then $h > 0$ and $\aleph = 1$. If they have a regular home then their $h > 0$ but $\aleph = 0$.

First stage: choice of non-home owner We begin the household problem by defining the choice-specific value function for a non-homeowner. This covers households that rent and face the choice between renting again, buying a regular/solar home. Also, this value function also serves as a bridge state for households that have just sold their home.

$$\begin{aligned} v^{\text{rent}}(a,\eta,\theta) = \max_{c,e,s,a'} \; & U(c,e,s) + \beta\,\mathbb{E}\Big[W^n(a',\eta',\theta') \,\Big|\, \eta, p^e\Big] \\ \text{s.t.} \quad & w(1-\tau)y + a = c + p^r s + p^a a' + p^e e, \\ & (3),\ (4),\ \text{and}\ (8). \end{aligned} \tag{11}$$

$$\begin{aligned} v^{f-owner}(a,\eta,\theta) = \max_{c,e,s,a'} \; & U(c,e,h) + \beta\,E\big[W^{owner-regular}(a',\eta',\theta',h',m') \mid \eta, p^e\big] \\ \text{s.t.} \quad & w(1-\tau)y + a + m' = c + p^h h + p^a a' + p^e e + \delta h, \\ & (3),\ (4), (8), (5),\ \text{and}\ (6) \end{aligned} \tag{12}$$

$$\begin{aligned} v^{f-owner-solar}(a,\eta,\theta) = \max_{c,e,s,a'} \; & U(c,e,h) + \beta\,E\big[W^{owner-solar}(a',\eta',\theta',h',m') \mid \eta, p^e\big] \\ \text{s.t.} \quad & w(1-\tau)y + a + m' + p^e f^e(h) = c + e^s h + p^a a' + p^e e + \delta h, \\ & (3),\ (4), (8), (5),\ \text{and}\ (6) \end{aligned} \tag{13}$$

$$V^n(u,a,\eta,\theta) = \max\big[V^{rent}(a,\eta,\theta)+u^r, V^{f-own}(a,\eta,\theta)+u^{f-own}, V^{f-own-solar}(a,\eta,\theta)+u^{f-own-solar}\big] \tag{14}$$

u^r, $u^{f\text{-}own}$, and $u^{f\text{-}own\text{-}solar}$ follow a Type-I extreme value distribution with scale parameter Λ^r.

Second stage: regular owner problem In this section, we define the choice-specific (conditional) value function for a homeowner in the regular state. The homeowner has three options: sell, repay the mortgage (or stay if no mortgage is outstanding), or install solar panels.

$$\begin{aligned} v^{sell}(a,\eta,\theta,h,m) &= W^n(\hat{a},\eta,\theta) \\ \text{s.t.} \quad \hat{a} &= (1-\tau)yw + (1-\delta-\kappa)p^h + (1+r)a - m(1+r_m) \end{aligned} \tag{15}$$

$$\begin{aligned} v^{repay}(a,\eta,\theta,h,m) = \max_{c,e,s,a'} \quad & U(c,h) + \beta\, E\big[W^{owner-regular}(a',\eta',\theta',h',m') \mid \eta, p^e\big] \\ \text{s.t.} \quad & w(1-\tau)y + a = c + p^h h + a' p_b + p^e e - \pi_m, \\ & (3),\ (4),(8),(5),(6) \text{ and } (7)' \end{aligned} \tag{16}$$

$$\begin{aligned} v^{install}(a,\eta,\theta,h,m) = \max_{c,e,s,a'} \quad & U(c,e,h) + \beta\, E\big[W^{owner-solar}(a',\eta',\theta',h,m',\aleph') \mid \eta, p^e\big] \\ \text{s.t.} \quad & wy - \chi + \delta p^h h + a + p^e F^e(h) = c + p_b a' + p^e e - \pi_m + p^p h \\ & (3),\ (4),(8),(5),(6),(10) \text{ and } (7) \end{aligned} \tag{17}$$

$$\begin{aligned} &V^{onwer-regular}(\nu,a,\eta,\theta,h,m) = \\ &\qquad \max\big[v^{sell}(a,\eta,\theta) + \nu^{sell}, v^{repay}(a,\eta,\theta,h,m) + \nu^{repay}, v^{install}(a,\eta,\theta,h,m) + \nu^{install} + \omega\big] \end{aligned} \tag{18}$$

ν^{sell}, ν^{repay}, and $\nu^{install}$ follow a Type-I extreme value distribution with scale parameter Λ^o.

Third stage: solar home owner problem Solar homeowners have two options. They can sell or repaying their outstanding mortgage.

$$\begin{aligned} v^{sell}(a,\eta,\theta,h,m) &= W^n(\hat{a},\eta,\theta) \\ \text{s.t.} \quad \hat{a} &= (1-\tau)yw + (1-\delta-\kappa)p^s + (1+r)a - m(1+r_m) \end{aligned} \tag{19}$$

$$
\begin{aligned}
v^{repay}(a,\eta,\theta,h,m) = \max_{c,e,s,a'} \quad & U(c,e,h) + \beta\, E\big[W^{owner-solar}(a',\eta',\theta',h,m',\aleph') \mid \eta, p^e\big] \\
\text{s.t.} \quad & w(1-\tau_s)y + a + p^e F^e(h) = c + \delta p^s h + p_b a' + p^e e \\
& (3),\ (4), (8), (5), (6),\ \text{and}\ (7).
\end{aligned} \tag{20}
$$

$$
\begin{aligned}
V^{onwer-solar}(\epsilon, a,&\eta,\theta,h,m) = \\
& \max\big[v^{sell}(a,\eta,\theta) + \epsilon^{sell}, v^{repay}(a,\eta,\theta,h,m) + \epsilon^{repay}\big]
\end{aligned} \tag{21}
$$

ϵ^{sell} and ϵ^{repay} follow a Type-I extreme value distribution with scale parameter Λ^o.

Continuation value This section we describe continuation values using the charateristic of type-I extream value distriction: $W^n, W^{owner-regular}, W^{owner-solar}$.

$$
\begin{aligned}
W^n(a,\eta,\theta) &= \Lambda^r\gamma + \Lambda^r \log\left[\sum_{i\in\mathcal{J}^r} \exp\left(\frac{v^i(a,\eta,\theta)}{\Lambda^r}\right)\right], \\
\mathcal{J}^r &= \{\text{rent, own-regular, own-solar}\}.
\end{aligned} \tag{22}
$$

$$
\begin{aligned}
W^{\text{owner-regular}}(a,\eta,\theta,h,m) &= \Lambda^o\gamma + \Lambda^o \log\left[\sum_{i\in\mathcal{J}^o} \exp\left(\frac{v^i(a,\eta,\theta,h,m)}{\Lambda^o}\right)\right], \\
\mathcal{J}^o &= \{\text{sell, repay, install}\}.
\end{aligned} \tag{23}
$$

$$
\begin{aligned}
W^{\text{owner-solar}}(a,\eta,\theta,h,m,\aleph) &= \Lambda^s\gamma + \Lambda^s \log\left[\sum_{i\in\mathcal{J}^s} \exp\left(\frac{v^i(a,\eta,\theta,h,m,\aleph)}{\Lambda^s}\right)\right], \\
\mathcal{J}^s &= \{\text{sell, repay}\}.
\end{aligned} \tag{24}
$$

Choice probabilty Let $\mathcal{J}^r = \{\text{rent, own-regular, own-solar}\}$, $\mathcal{J}^o = \{\text{sell, repay, install}\}$, and $\mathcal{J}^s = \{\text{sell, repay}\}$. Then the conditional choice probabilities are

$$P^{n,i}(a,\eta,\theta) = \frac{\exp\left(\frac{v^i(a,\eta,\theta)}{\Lambda^r}\right)}{\sum_{j\in\mathcal{J}^r}\exp\left(\frac{v^j(a,\eta,\theta)}{\Lambda^r}\right)}, \qquad i \in \mathcal{J}^r, \tag{25}$$

$$P^{o,i}(a,\eta,\theta,h,m) = \frac{\exp\left(\frac{v^i(a,\eta,\theta,h,m)}{\Lambda^o}\right)}{\sum_{j\in\mathcal{J}^o}\exp\left(\frac{v^j(a,\eta,\theta,h,m)}{\Lambda^o}\right)}, \qquad i \in \mathcal{J}^o, \tag{26}$$

and

$$P^{s,i}(a,\eta,\theta,h,m,\aleph) = \frac{\exp\left(\frac{v^i(a,\eta,\theta,h,m,\aleph)}{\Lambda^s}\right)}{\sum_{j\in\mathcal{J}^s}\exp\left(\frac{v^j(a,\eta,\theta,h,m,\aleph)}{\Lambda^s}\right)}, \qquad i \in \mathcal{J}^s. \tag{27}$$

4 Calibration

The calibration is reported in Table 1. As a starting point, we adopt standard values from the literature for parameters that are exogenously determined. We then calibrate the three scale parameters, the additive preference shifter for solar installation, and the minimum housing size to match the homeownership rate, the solar installation rate, and stage-specific moving rates.

The unit price of solar panels, p^p, is calibrated to match an installation cost equal to 37% of median income for a minimum-sized house. In addition, the productivity parameter of solar panels, Q, is calibrated so that the total value of electricity generated by a minimum-sized house equals 2% of median income.

5 Baseline Results

We take the economy before the removal of the tax credit as the baseline. The model results for this baseline economy are summarized in Table 2. The first panel reports the aggregate solar installation rate in the steady state and compares mortgage borrowing between solar owners and regular homeowners. We calibrate the model to match a solar installation rate of 4%. The loan-to-value ratio of solar owners is nearly half that of regular homeowners.

Table 1: Tentative calibration parameters

Symbol	Description	Value	Internal
Preference			
β	Discount factor	0.93	N
σ	Elasticity of substitution (CES)	0.8	N
γ	CRRA coefficient	2	N
ϕ_c	CES weight on consumption	0.78	N
ϕ_e	CES weight on electricity	0.02	N
ϕ_s	CES weight on housing services	0.2	N
Λ^r	Scale parameter (non-owner)	0.005	Y
Λ^o	Scale parameter (regular owner)	0.005	Y
Λ^s	Scale parameter (solar owner)	0.0005	Y
ω	Additive solar adoption preference	-0.025	Y
ω'	Additive solar adoption preference(counterfactual)	-0.025+0.0185	Y
Housing			
$h_{\min}$	U.S. 25th-percentile housing size	4	Y
P_h	House price per unit	1	Normalized
P_r	Rent price per unit	0.03	N
δ_h	Housing depreciation	0.05	N
κ	Transaction cost	0.07	N
Solar and Electricity			
α_s	Solar premium on house	0.035	N
p^p	Installation cost per unit of housing	0.0925	Y
ρ_e	AR(1) persistence (electricity price)	0.9	N
σ_e	AR(1) innovation s.d. (electricity price)	0.001	N
Q	Electricity production parameter	0.005	Y
Financial Market			
r_m	Mortgage interest rate	0.03	N
r_b	Risk-free rate	0.03	N
λ^l	Minimum down-payment ratio	0.1	N
λ^{π_m}	Maximum debt-to-income ratio	0.5	N
Wage and Tax			
τ_y	Labor income tax rate	0.25	N
w	Aggregate income	1	Normalized
ρ_η	AR(1) persistence (permanent income)	0.9	N
σ_η	AR(1) innovation s.d. (permanent income)	0.2	N
m_θ	Mean of transitory income shock	0	N
σ_θ	Variance of transitory income shock	0.42	N
$\mathcal{C}$	Tax credit ratio	0.3	N

The second panel reports solar installation rates by housing size. The results show substantial variation in installation rates across house sizes. This pattern likely reflects the correlation between housing size choices and earnings. Higher-income households face stronger incentives from the tax credit and face fewer financial constraints when installing solar panels.

The third panel shows that about 75% of houses with solar panels are owned by households with income above the median. The fourth panel presents the law of motion across housing states. In the baseline economy, 88% of renters remain renters, while the remainder transition to regular homeownership; no renter transitions directly to solar homeownership. Among regular homeowners, 88% remain in their homes and continue repaying their mortgages, while about 11% sell their current homes. In addition, nearly 0.3% of regular homeowners choose to install solar panels.

Figure 1 shows the solar adoption rate by asset level for different combinations of state variables. Panel (a) of Figure 1 presents the installation rate by asset holdings for the entry-level home, h_2, while panel (b) of Figure 1 presents the corresponding pattern for the larger home, h_3. Figure 1 exhibits a hump-shaped pattern over most of the asset grid, with a jump in the right tail. The hump shape arises because households need to accumulate some assets in order to finance the solar installation cost. However, as assets increase further, households lose some incentive to adopt solar because they can more easily afford conventional electricity expenses. Finally, once households accumulate sufficiently high asset holdings, the solar adoption rate rises again, generating the jump in the right tail. Panel (b) of Figure 1 also displays a hump-shaped pattern for the same reason, but it does not exhibit a jump.

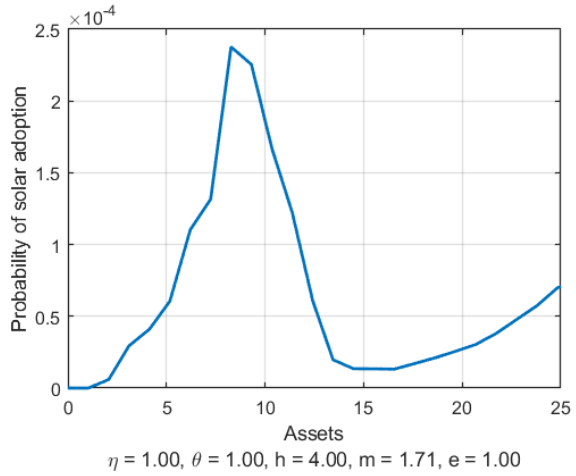
Figure 2 breaks down Figure 1 by persistent income states. It demonstrates that the dominant income group varies with asset levels: while the highest-income group leads at lower asset levels, lower-income groups become dominant as asset holdings grow.

Figure 3 decompose Figure 1 by electricity price states and clearly show that higher electricity prices lead to higher installation rates.

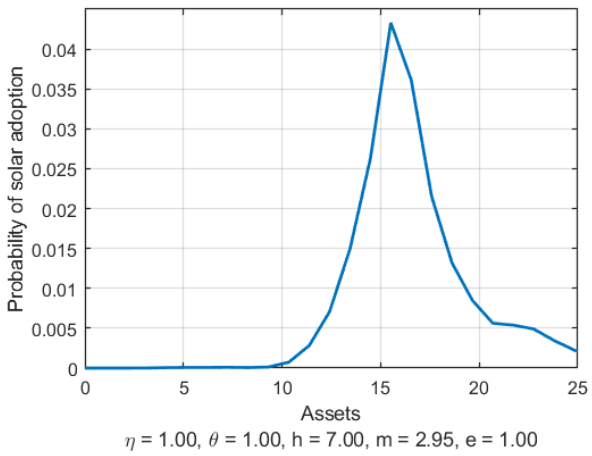
Previously, the non-monotonic (hump-shaped) relationship between solar adoption and asset holdings was attributed solely to a combination of low electricity price sensitivity and high upfront installation costs. However, these factors alone do not sufficiently explain the phenomenon. By

Table 2: Baseline model: 30% Tax Credit

Stationary moments	
Homeownership rate (reg+solar)	0.6498
Solar owners / population	0.0268
Solar owners / owners	0.0412
Avg LTV (owners overall)	0.3822
Avg LTV (regular owners)	0.3898
Avg LTV (solar owners)	0.2041
Solar share by housing size (h)	
h_{min}	0.00114
h_{max}	0.07651
Income group's share of total solar adoption (η)	
$\eta = 0.1285$	0.03886
$\eta = 0.3584$	0.23018
$\eta = 1.0000$	0.42959
$\eta = 2.7898$	0.27130
$\eta = 7.7831$	0.03005
Laws of motion (mass-weighted)	
From renters ($\phi = 1$)	
rent $\rightarrow$ rent	0.88464
rent $\rightarrow$ reg	0.11536
rent $\rightarrow$ sol	0.00000
From regular owners ($\phi = 2$)	
reg $\rightarrow$ rent (sell)	0.11586
reg $\rightarrow$ reg (repay)	0.88130
reg $\rightarrow$ sol (install)	0.00284
From solar owners ($\phi = 3$)	
sol $\rightarrow$ rent (sell)	0.06583
sol $\rightarrow$ sol (repay)	0.93417

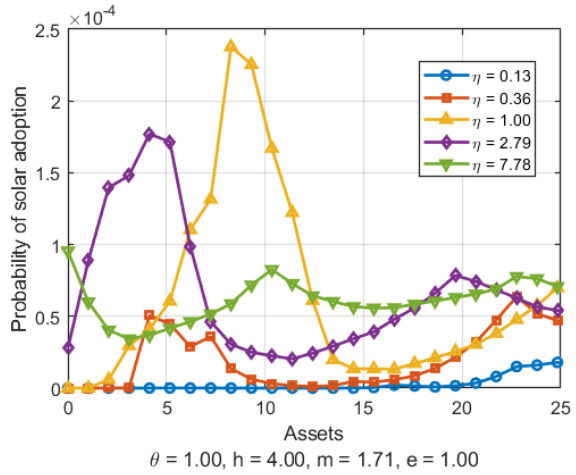


(a) Solar adoption rate across assets for housing size h_2

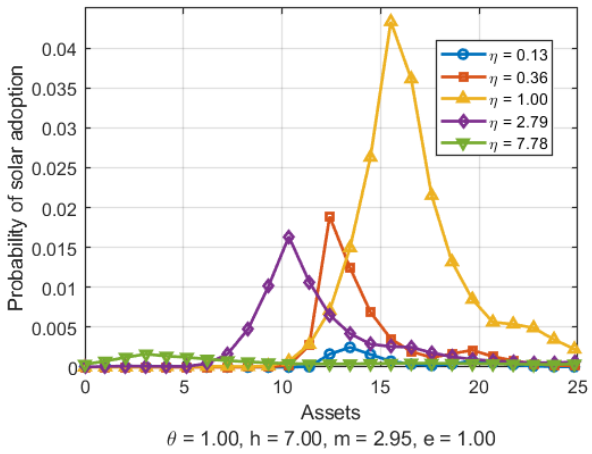


(b) Solar adoption rate across assets for housing size h_3

Figure 1: Solar adoption rates across assets by housing size

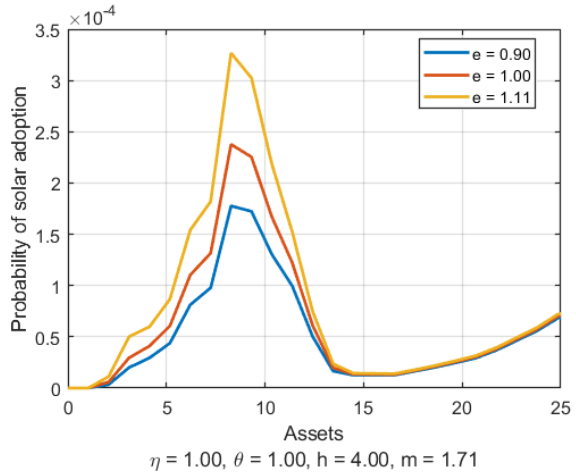


(a) Solar adoption rate across persistent income for housing size h_2

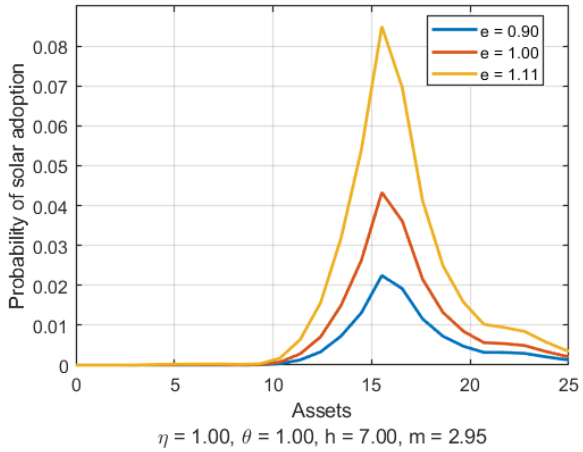


(b) Solar adoption rate across persistent income for housing size h_3

Figure 2: Solar adoption rates across persistent income by housing size



(a) Solar adoption rate across assets and electricity price for housing size h_2



(b) Solar adoption rate across assets and electricity price for housing size h_3

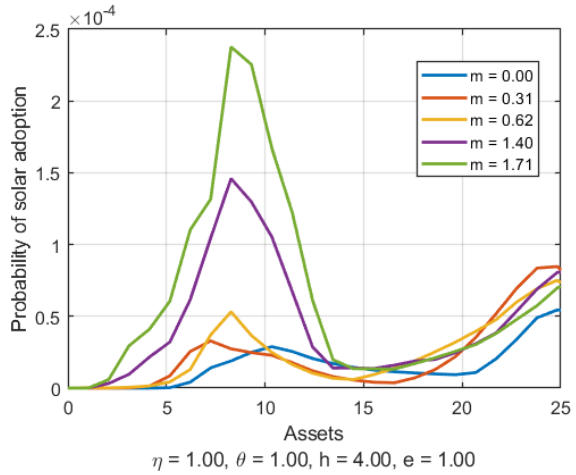
Figure 3: Solar adoption rates across assets and electricity prices by housing size

disaggregating the adoption rate by mortgage debt, Figure 4 reveals a more nuanced mechanism: the hump-shape is significantly more pronounced among households with high remaining mortgage balances. Conversely, households with low mortgage debt exhibit a near-linear relationship between asset holdings and adoption rates.

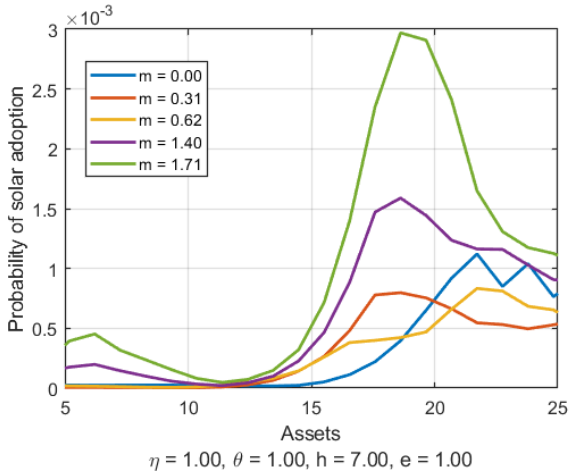
This divergence suggests an "equity-accumulation" motive. Given an exogenous 3.5% house price premium associated with solar installations, adoption serves as a strategic lever to increase home equity. For highly leveraged households, this marginal increase in property value provides a greater relative benefit to their net equity position than for those with low debt. Consequently, these households prioritize "upgrading" their primary illiquid asset—the home—over traditional liquid asset accumulation.

6 Counterfactual Simulation

The counterfactual strategy is straightforward. First, we remove the tax credit and compute a new steady state under the no-tax-credit policy. Second, after removing the tax credit, we increase the exogenous preference, ω, so as to match the same aggregate solar installation rate as in the baseline. We found that ω should be increased by 0.0185. So, in the third experiment $\omega = -0.025 + 0.0185 = -0.0065$. Comparing the baseline with the first counterfactual allows us



(a) Solar adoption rate across assets and mortgage debt for housing size h_2



(b) Solar adoption rate across assets and mortgage debt for housing size h_3

Figure 4: Solar adoption rates across assets and mortgage debt by housing size

to identify the long-run effect of the tax credit on household decision-making. Comparing the baseline with the third economy allows us to examine the different implications of achieving the same aggregate solar installation rate through pecuniary and non-pecuniary incentives, namely tax credits versus a universal preference shift. Finally, we calculate the willingness to pay associated with the required preference shift in terms of the average installation cost.

Table 3 summarizes these counterfactual analyses. Without the tax credit, only 0.15% of homes install solar panels. In addition, because of the financial constraint associated with the upfront cost, most installations are concentrated among households with larger homes and higher incomes. The law of motion is broadly similar in this case, but the solar installation rate declines to about one-thirtieth of the baseline level once the tax credit is removed, leading to a much lower aggregate installation rate.

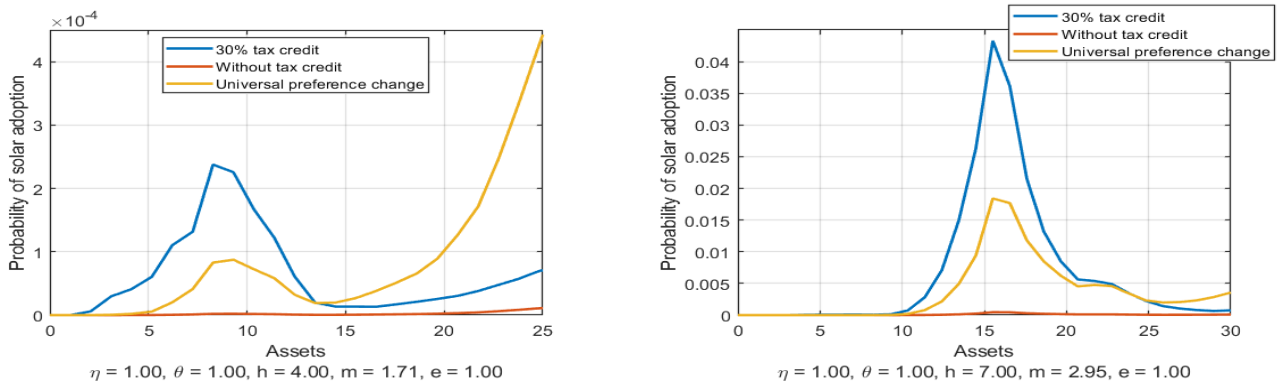
The last column reports the results for the universal preference change. We calibrate the additional preference term to match the baseline solar installation rate. Notably, the loan-to-value ratio of solar homes is only about 60% of the baseline level. This is because, without the tax credit, financially constrained households are excluded from solar ownership, while richer households enter into solar ownership after the preference shift, even though they would have been able to afford installation earlier but chose not to do so. The solar installation rates by housing size and persistent income state in the second and third panels support this result: households with

Table 3: Counterfactual Simulation

	30% Tax Credit	**No Tax Credit**	**Universal Preference Change**
Stationary moments			
Homeownership rate (reg+solar)	0.6498	0.6453	0.6489
Solar owners / population	0.0268	0.0009	0.0294
Solar owners / owners	0.0412	0.0015	0.0454
Avg LTV (owners overall)	0.3822	0.3852	0.3813
Avg LTV (regular owners)	0.3898	0.3856	0.3934
Avg LTV (solar owners)	0.2041	0.1241	0.1265
Solar share by housing size (h)			
h_{min}	0.00114	0.00001	0.00024
h_{max}	0.07651	0.00275	0.08553
Income group's share of total solar adoption (η)			
$\eta = 0.1285$	0.0387	0.0448	0.0398
$\eta = 0.3584$	0.2301	0.2000	0.1917
$\eta = 1.0000$	0.4295	0.3567	0.3614
$\eta = 2.7898$	0.2713	0.2930	0.3021
$\eta = 7.7831$	0.0303	0.1052	0.1048
sum	1.0000	1.0000	1.0000
Laws of motion (mass-weighted)			
From renters ($\phi = 1$)			
rent $\to$ rent	0.88464	0.88499	0.88510
rent $\to$ reg	0.11536	0.11501	0.11490
rent $\to$ sol	0.00000	0.00000	0.00000
From regular owners ($\phi = 2$)			
reg $\to$ rent (sell)	0.11586	0.11493	0.11645
reg $\to$ reg (repay)	0.88130	0.88499	0.88084
reg $\to$ sol (install)	0.00284	0.00008	0.00272
From solar owners ($\phi = 3$)			
sol $\to$ rent (sell)	0.06583	0.05709	0.05688
sol $\to$ sol (repay)	0.93417	0.94291	0.94312

larger homes and higher incomes exhibit a stronger increase in solar adoption under the preference shift. The laws of motion are also similar across the two economies, which helps maintain similar aggregate outcomes.

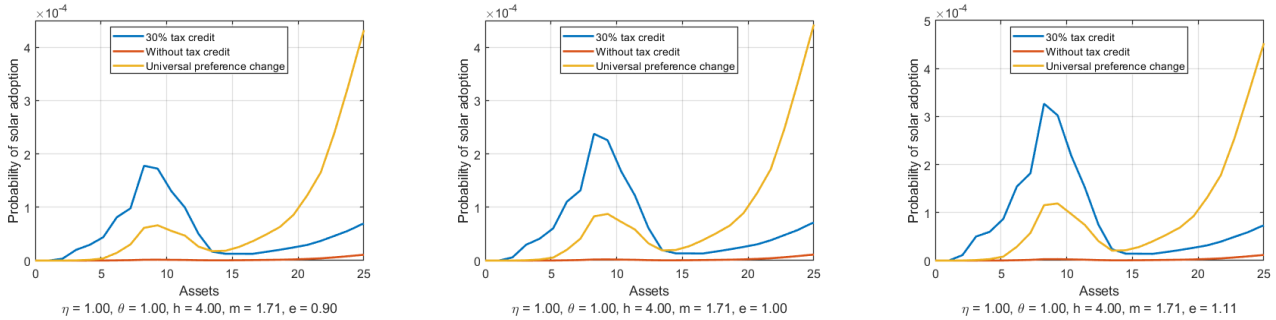
Figure 5 presents the probability of solar installation by asset level for the baseline and the counterfactual economies. At lower asset levels, the tax-credit economy dominates the preference-boosted economy, whereas at higher asset levels the preference shift generates a higher probability of installation. Figure 6 recalculate Figure 5 for different electricity price states and clearly show that higher electricity prices lead to higher installation rates in all experiments.



(a) Counterfactual solar adoption across assets at h_2

(b) Counterfactual solar adoption across assets at h_3

Figure 5: Counterfactual solar adoption across assets by housing size



(a) Counterfactual solar adoption across assets at electricity price e_1

(b) Counterfactual solar adoption across assets at electricity price e_2

(c) Counterfactual solar adoption across assets at electricity price e_3

Figure 6: Counterfactual solar adoption across assets by electricity price

We quantify the non-pecuniary incentive required to offset the removal of the 30% tax credit. First, we solve the model under the baseline policy with the tax credit and compute the stationary

distribution and aggregate solar adoption rate. We then remove the tax credit, re-solve the model, and introduce a universal non-pecuniary shifter $K = |\omega - \omega'|$ that enters additively in the utility (value) of the *install* option for regular homeowners. We choose K so that the stationary aggregate solar adoption rate in the no-credit economy matches the baseline adoption rate.

To interpret the estimated K in monetary terms, we compute a money-metric willingness-to-pay (WTP) using the model's marginal value of liquid resources. Because K shifts only the install option, its effect on the regular-owner inclusive value $W_{\text{reg}}(x)$ is $\Delta W_{\text{reg}}(x) \approx p_{\text{inst}}(x)\, K$, where $p_{\text{inst}}(x)$ is the model-implied installation probability at state x. Let $\partial W_{\text{reg}}(x)/\partial a$ denote the marginal increase in W_{reg} from one additional unit of liquid assets a. The state-by-state money-metric equivalent is therefore

$$\text{WTP}(x) \approx \frac{\Delta W_{\text{reg}}(x)}{\partial W_{\text{reg}}(x)/\partial a} = \frac{p_{\text{inst}}(x)\, K}{\partial W_{\text{reg}}(x)/\partial a},$$

and we report an average WTP by integrating $\text{WTP}(x)$ over the stationary distribution (optionally emphasizing marginal adopters via $p_{\text{inst}}(x)\big(1 - p_{\text{inst}}(x)\big)$ weights). Finally, we find that the average WTP is 4.97% for the cost of solar installation.

7 Conclusion

In light of the growing urgency surrounding climate change and the global energy crisis, political discourse is not always aligned with the necessary pace of action. Given this urgency and the possibility of fiscal shifts—such as the potential abolition of tax credits—it is essential to evaluate the efficacy of current policy mechanisms. By developing a frontier discrete-choice heterogeneous-agent model that incorporates realistic solar adoption processes, tax credits, and household borrowing constraints, we provide a deeper understanding of how households respond to policy interventions given their specific income, wealth, and electricity price profiles.

First, we shed light on the heterogeneous nature of household solar adoption. Interestingly, the probability of solar adoption follows a hump-shaped in liquid assets: insufficient liquid assets impose financial constraints, while excessive liquidity reduces the incentive to respond to fluctuations in electricity prices. Furthermore, higher-income households exhibit a higher adoption rate under

current tax credit schemes due to the combined benefits of affordability and tax optimization.

We find that a "Universal Preference Change" is highly effective in promoting solar adoption among wealthier households. These individuals possess the financial capacity for adoption but may have previously abstained due to non-pecuniary barriers.

There are several promising directions for future research using this model. First, we can evaluate alternative subsidies, such as discounted mortgage rates. Second, given that our model explicitly includes housing, we can explore how frictions—such as the inability to detach solar panels or the lack of a secondary market—hinder adoption. Third, it would be valuable to extend this to an overlapping-generations (OLG) framework to analyze how age-related factors, such as the time horizon for breaking even versus the probability of moving, affect adoption. Finally, we can investigate policies aimed at incentivizing landlords to install solar panels on rental properties.

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