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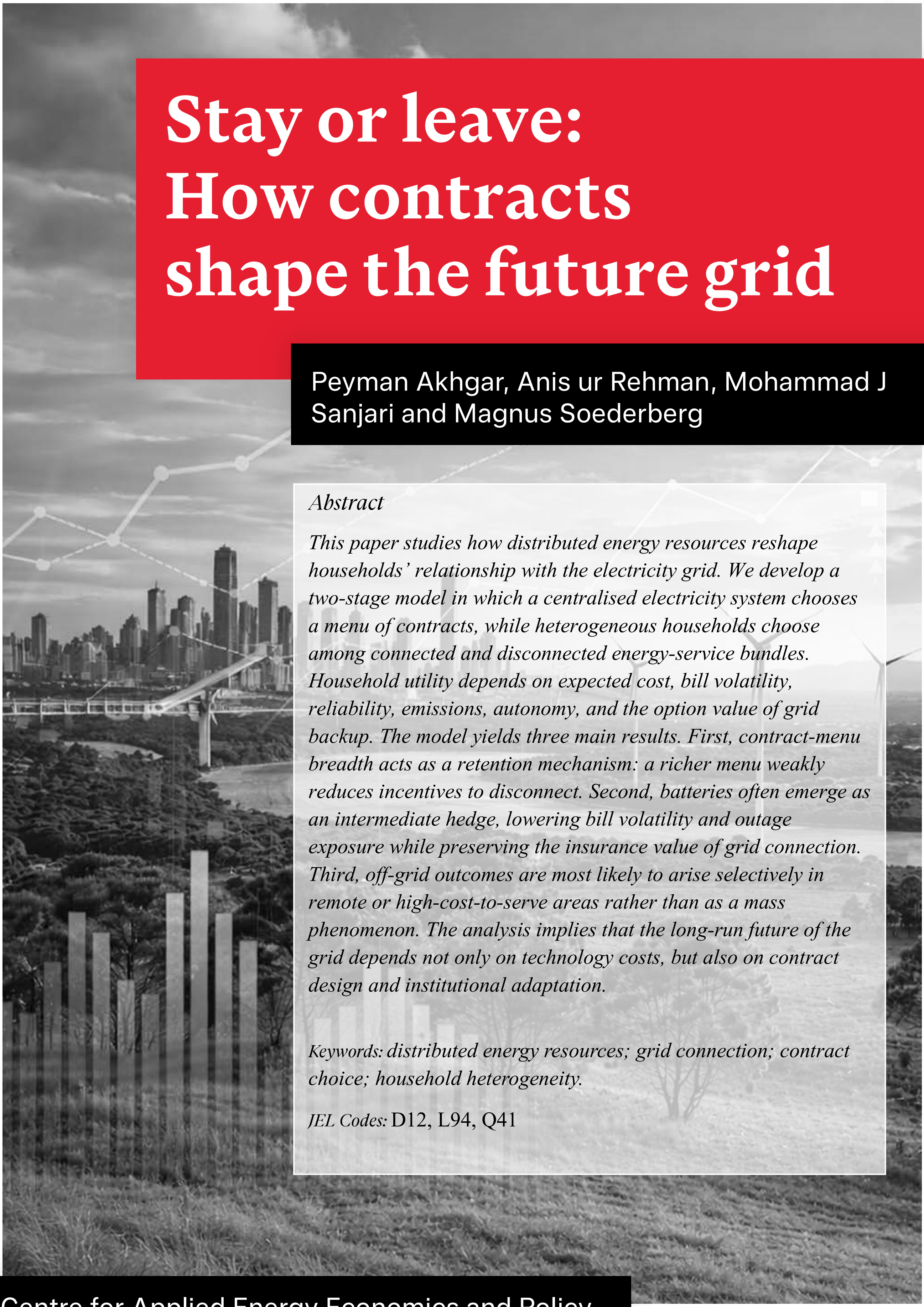

Stay or leave: How contracts shape the future grid

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Abstract

This paper studies how distributed energy resources reshape households' relationship with the electricity grid. We develop a two-stage model in which a centralised electricity system chooses a menu of contracts, while heterogeneous households choose among connected and disconnected energy-service bundles. Household utility depends on expected cost, bill volatility, reliability, emissions, autonomy, and the option value of grid backup. The model yields three main results. First, contract-menu breadth acts as a retention mechanism: a richer menu weakly reduces incentives to disconnect. Second, batteries often emerge as an intermediate hedge, lowering bill volatility and outage exposure while preserving the insurance value of grid connection. Third, off-grid outcomes are most likely to arise selectively in remote or high-cost-to-serve areas rather than as a mass phenomenon. The analysis implies that the long-run future of the grid depends not only on technology costs, but also on contract design and institutional adaptation.

Keywords: distributed energy resources; grid connection; contract choice; household heterogeneity.

JEL Codes: D12, L94, Q41

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1 Introduction

Electricity systems in advanced economies have historically been organised around centralised generation, one-way power flows, and retail arrangements that pool reliability and recover network costs through tariff structures that are only partly tailored to individual households. The diffusion of distributed energy resources (DER), including rooftop photovoltaic systems, behind-the-meter batteries, electric vehicles, and digitally enabled demand response, alters this architecture by making the household's degree of reliance on the centralised system increasingly a matter of economic choice rather than technological necessity. Australia provides a particularly informative case, where rooftop solar reached four million installations by late 2024, equivalent to roughly one in three homes, while household battery uptake accelerated markedly after certificate eligibility was extended in mid-2025 (Australian Government, 2024; Clean Energy Regulator, 2025).

A prominent narrative in policy and industry debate is that falling photovoltaic and storage costs will eventually induce large-scale household disconnection from the grid. Yet both theory and evidence suggest that complete disconnection is unlikely to be the dominant adjustment margin for most households. Recent engineering-economic modelling for Europe shows that off-grid self-sufficiency can be technically feasible but is economically attractive mainly for a relatively small subset, often requiring a substantial willingness to pay for autonomy (Kleinebrahm et al., 2023). In practice, stand-alone systems are concentrated where conventional supply is especially costly and fragile, namely in remote and high-cost-to-serve locations with long feeder lines, low customer density, and elevated outage exposure.[1] The relevant question is therefore not simply whether households disconnect, but how the boundary between continued connection, partial self-supply, and full disconnection is determined.

This paper addresses that question by focusing on three margins of adjustment. First, whether households remain connected to the grid. Second, which connected bundle they choose, such as grid-only supply, grid plus photovoltaic generation, or grid plus photovoltaic generation and storage. Third, where the private incentive to disconnect becomes sufficiently strong that stand-alone supply dominates continued connection. Analysing these margins requires taking heterogeneity seriously. Households differ in their valuation of expected expenditure, bill volatility, reliability, emissions, and autonomy. In addition, the empirical literature shows that retail electricity consumers often face substantial search, switching, and information frictions, and do not necessarily respond to nonlinear tariffs in the manner implied by fully informed optimisation (Ito, 2014; Hortaçsu et al., 2017). These frictions are important because they shape both household responses to tariff complexity and the feasible scope for differentiated retail offerings.

Sections 3 and 4 interpret the electricity system as a platform that offers a menu of contracts to heterogeneous households, while households choose among endogenous combinations of technology and contract. In conceptual terms, this connects the analysis to the economics of two-sided platforms and to the theory of nonlinear pricing and screening. Platform operators must determine how to attract and retain different user groups, while differentiated menus are used to accommodate heterogeneity in willingness to pay and usage characteristics (Rochet and Tirole, 2003; Mussa and Rosen, 1978; Armstrong, 2006). In the present setting, the relevant interaction is between households that can increasingly self-supply and a centralised electricity system that benefits from continued participation, flexibility, and efficient cost recovery.

We formalise this interaction in a two-stage model. In the first stage, the centralised system chooses the breadth and structure of a contract menu, including fixed and volumetric charges, time variation, export remuneration, and compensation for flexibility provision, subject to an administrative and implementation cost of offering and communicating additional products. In the second stage, heterogeneous households choose among a finite set of electricity-service bundles and, conditional on remaining connected, select the contract that maximises their certainty-equivalent utility. Within that utility representation, bill volatility enters as a risk penalty and reliability enters through a convex outage-loss term. This formulation makes it possible to distinguish analytically between two objects that are often conflated in less formal discussions. First, autonomy, understood as the value attached to control and reduced dependence on centralised decision-making, and second, the option value of grid backup.

The Australian institutional setting gives this two-stage representation particular empirical relevance. Long-horizon system planning in the National Electricity Market now treats consumer resources as systemically material. The 2024 Integrated System Plan projects strong growth in consumer energy resources and states that coordinated household batteries could offset approximately $4.1 billion of grid-scale storage investment (Australian Energy Market Operator, 2024a; Australian

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[1] *Western Power has installed more than 320 stand-alone power systems in regional Western Australia and presents them as safer, more reliable, and lower-cost alternatives to maintaining long radial lines in remote areas (Western Power, n.d.).*

Energy Market Operator, 2024b). At the same time, smart-meter reforms expand the feasible set of household contracts by targeting universal deployment by 2030 and strengthening customer protections around tariff changes and access to meter data.[2] These developments enlarge the set of feasible contracts, but they also increase the importance of consumer understanding, contract complexity, and institutional trust.

The model yields four central results. First, contract-menu breadth operates as a retention mechanism. Expanding the menu weakly increases each household's maximum attainable utility while connected, and therefore weakly reduces the incentive to disconnect. Second, because connection burdens are partly geographic, there exist thresholds in remoteness and cost-to-serve beyond which off-grid or stand-alone supply dominates, implying that disconnection should be spatially concentrated rather than a mass phenomenon. Third, behind-the-meter storage emerges as an intermediate hedge that reduces bill volatility and outage exposure while preserving the insurance value of grid connection. Consequently, adverse changes in export remuneration or volatility exposure may induce re-optimisation within the set of connected bundles, rather than immediate disconnection. Fourth, the platform chooses menu breadth by balancing improved matching under heterogeneity against the costs associated with implementation, communication, metering, and consumer complexity.

The paper is closely related to three literatures, but differs from each in a central respect. The distributed-generation literature shows that tariff design and storage economics materially shape household incentives to adopt photovoltaic systems and batteries, yet it generally treats the surrounding contract environment as exogenous rather than chosen strategically by the centralised system (Borenstein, 2017; Schill et al., 2017; Günther et al., 2021). The retail electricity literature shows that nonlinear pricing is often imperfectly understood and that consumer inertia can substantially weaken the effectiveness of tariff-based competition, but it does not analyse how those frictions interact with DER adoption and off-grid outside options (Ito, 2014; Hortaçsu et al., 2017). The reliability literature studies how market design affects reliability provision and investment incentives, while platform and screening theory explains why differentiated menus arise under heterogeneity. However, these approaches have not been integrated in a framework where households choose among connected and disconnected energy-service bundles and where the value of connection depends jointly on backup, pricing, and flexibility opportunities (Joskow and Tirole, 2007; Rochet and Tirole, 2003; Mussa and Rosen, 1978; Armstrong, 2006). The contribution of this paper is therefore to endogenise the contract menu of the centralised system in a heterogeneous-household DER setting, thereby linking tariff design, reliability, and disconnection risk within a single tractable framework.

Section 2 reviews the principal stylised facts and institutional developments that motivate the model. Section 3 presents the two-stage framework of household choice and platform adaptation. Section 4 maps empirical evidence into model primitives and interprets the resulting equilibrium trajectories. Section 5 concludes.

2 Stylised facts and institutional context

The transition from a centralised electricity system to one with widespread distributed energy resources (DER) is a global phenomenon, not an Australian anomaly. Across advanced economies, distributed PV, behind-the-meter batteries, electric vehicles, smart appliances and digitally enabled demand response are expanding the set of energy-service bundles available to households. The International Energy Agency now treats DER as a system-level resource rather than a niche technology class, and emphasises that digitalisation and local flexibility are becoming central to power-system operation as electrification and variable renewables expand (International Energy Agency, 2022; International Energy Agency, 2024). Australia is an important case because adoption has been unusually rapid and policy reform unusually explicit, but similar underlying pressures are visible in Europe and North America as retail pricing, export compensation and smart-meter regulation are redesigned around two-way flows and more active consumers (European Union, 2019; Australian Energy Market Operator, 2024).

A first stylised fact is that households are heterogeneous, both in their preferences and in the private economics of adoption. The empirical literature shows that adoption of rooftop PV and storage is shaped by expected bill savings, subsidies, tariff design, housing conditions and local prices, but not by these factors alone. In California, for example, upfront subsidies had large effects on residential solar uptake, while the distribution of adopters reflected both incentives and household characteristics (Hughes and Podolefsky, 2013). More generally, the private returns to residential solar depend heavily on the structure of retail tariffs, tax incentives and rebates, implying that the same technology can be highly attractive for some households and much less so for others (Borenstein, 2017). At the same time, the broader prosumer literature shows that households often value non-price attributes such as environmental performance, control and participation, though the weight attached to those motives varies

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[2] *The institutional significance of these reforms is also reflected in the Australian regulatory impact process surrounding accelerated smart-meter deployment (Office of Impact Analysis, 2024).*

considerably across consumers and contexts (Parag and Sovacool, 2016). This heterogeneity is central for the present paper because it implies that no single 'representative household' can capture the relevant margins of choice.

A second stylised fact is that the value of being connected to the grid cannot be reduced to average annual expenditure. Reliability and backup value matter, and they matter nonlinearly. Evidence on outage valuation shows that households are willing to pay to avoid interruptions, with willingness to pay increasing sharply with duration and being higher for unplanned outages than for planned ones (Carlsson and Martinsson, 2007; 2008). At the market-design level, reliability is also inseparable from prices, reserve arrangements and investment incentives. Wholesale price caps, capacity obligations and emergency protocols all affect whether competitive markets produce adequate reliability ex ante (Joskow and Tirole, 2007). For households, this implies that the grid provides an insurance service even when day-to-day self-supply is technically feasible. Local batteries can reduce exposure to outages and price spikes, but full self-sufficiency still requires covering rare low-generation and high-demand states, which is why grid connection often remains valuable even in high-DER environments (Schill et al., 2017).

A third stylised fact is that tariff and contract design shape the connected bundles households choose. The economics literature has shown that consumers do not always respond to tariffs in the way standard models assume. Under nonlinear electricity pricing, households may respond more to average price than to marginal price, so even well-intended tariff reform can have weaker or different behavioural effects than regulators expect (Ito, 2014). In retail electricity markets, search frictions, inattention and incumbent advantages can also substantially limit switching and dampen the gains from nominal competition (Hortaçsu et al., 2017). These behavioural frictions matter directly for the design of a differentiated contract menu. In parallel, the energy-economics literature shows that the profitability of residential PV and storage is highly sensitive to the mix of volumetric charges, fixed charges and feed-in compensation. Lower feed-in tariffs tend to reduce PV investment, while higher fixed charges reduce incentives for self-consumption and battery investment, even when the underlying technologies continue to improve (Borenstein, 2017; Günther et al., 2021). The implication is that connected household choices are shaped not only by technology costs, but also by the institutional design of the tariff environment.

This point is reinforced by recent international experience with dynamic pricing. In Europe, Directive (EU) 2019/944 explicitly requires that the regulatory framework enable suppliers to offer dynamic electricity price contracts and that customers with smart meters be able to request them (European Union, 2019). Yet actual household demand for such products remains limited and uneven. Recent evidence from Finland shows that, even after the 2021–2024 energy crises pushed retailers to promote dynamic tariffs more aggressively, stable flat-price contracts retained a dominant market position because of consumer risk concerns, retailer caution and institutional frictions in the relationship between retailers, networks and households (Numminen et al., 2025). This is also consistent with the broader empirical literature showing that consumer demand for time-of-use tariffs is highly heterogeneous and often constrained by complexity, salience, and perceived gains (Nicolson et al., 2018). This suggests that smart meters and digitalisation enlarge the feasible contract set, but do not eliminate concerns about complexity, risk exposure and consumer protection. In other words, a wider menu is feasible, but not without friction.

A fourth stylised fact is that off-grid and stand-alone outcomes are geographically differentiated rather than mass-market. In dense urban and suburban systems, the dominant margin is usually not full defection but partial self-supply with continued connection. Engineering-economic modelling for Europe shows that while many homes could technically become self-sufficient, full off-grid supply is economically attractive for only a limited subset even in 2050, and mainly where high electricity prices, favourable solar resources and lower seasonal mismatch combine with a willingness to pay a premium for autonomy (Kleinebrahm et al., 2023). By contrast, stand-alone systems can be privately or socially attractive in remote and high-cost-to-serve areas where long feeders, vegetation management, weather exposure and low customer density make conventional network service expensive and fragile. Western Power's stand-alone power systems in regional Western Australia provide a concrete example, as explained earlier. The relevant economic point is that "defection" is not a uniform process. It is heavily mediated by geography, network topology and the cost of maintaining connection.

Taken together, these stylised facts motivate the structure of Sections 3 and 4. Households differ in their valuation of expected bill level, bill volatility, reliability, emissions and autonomy. The grid retains value because it provides backup and insurance, tariff and contract design shape the connected bundles households select, and full disconnection is most relevant in locations where the cost of connection is unusually high. These are precisely the ingredients that motivate a two-stage framework in which the electricity system is modelled as a platform choosing a menu of contracts, while heterogeneous households choose among connected and disconnected energy-service bundles. The institutional relevance of that framework is especially clear in Australia, where the 2024 Integrated System Plan treats coordinated consumer resources as systemically material (Australian Energy Market Operator, 2024), while smart-meter reform expands the feasible set of differentiated household contracts.[3]

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[3] *Australian Energy Regulator links the rollout to broader tariff choice and improved access to meter data (Australian Energy Regulator, n.d.).*

3 An economic model of heterogeneous household choice

This section develops a two-stage model of household choice and platform adaptation. In stage 1, the centralised electricity system chooses a menu of contracts and pricing terms. In stage 2, heterogeneous households choose among electricity-service bundles, taking that menu as given. The objective is to reproduce three stylised facts already emphasised in Sections 1–2, i.e. widespread DER adoption, continued grid connection for most adopters, and selective off-grid solutions where network costs are sufficiently high (Australian Energy Market Operator, 2022; Kleinebrahm et al., 2023).[4]

3.1 Households, bundles, and contracts

Household i chooses one energy-service bundle $j \in \mathcal{J}$, where

$$\mathcal{J} = \{G, S, B, E, O\},$$

with:

- $G =$ grid only,
- S = grid + PV,
- B = grid + PV + battery,
- E = grid + PV + battery + EV,
- $O =$ off-grid / standalone system.

For connected bundles $j \in \mathcal{J}^c = \{G, S, B, E\}$, the household also chooses a contract $m \in \mathcal{M}$, where $\mathcal{M}$ is the menu offered by the centralised system. A contract may include, for example, a fixed charge, volumetric prices, dynamic-pricing terms, export remuneration, flexibility/VPP payments, green options, or reliability-related arrangements. For the off-grid bundle O, no grid contract is chosen.

Each bundle-contract pair (j, m) generates the following attributes:

μ_{ijm} = expected annual private cost,
σ_{jm}^2 = bill variance,
X_{jm} = outage burden or unserved energy,
e_{jm} = emissions intensity,
a_j = autonomy value,
b_j = backup/insurance value of remaining connected.

By construction, $b_O = 0$, while $b_j > 0$ for connected bundles. This captures the fact that autonomy and backup are distinct. A household may value independence from centralised rule-setting, but still attach substantial value to the grid as an insurance device during rare but severe low-generation or high-demand episodes (Australian Energy Market Operator, 2022; Kleinebrahm et al., 2023).[5]

To capture reliability in a way consistent with the empirical discussion, let outage losses be governed by a convex function $L(\cdot)$, with

$$L'(x) > 0, \quad L''(x) > 0.$$

This means that larger outages are disproportionately more costly than small, familiar outages. That matches the evidence that many households exhibit limited willingness to pay to avoid small baseline outages, but place substantial value on avoiding rare, high-impact outages (Australian Energy Regulator, 2024).

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[4] *See also Rocky Mountain Institute (2014) on the economics of selective grid defection, and Western Power and Ergon Energy on stand-alone systems in remote or high-cost-to-serve areas (Western Power, n.d.; Ergon Energy, n.d.).*

[5] *Rocky Mountain Institute (2014) similarly emphasises that the economics of defection depend on the value of retaining the grid as backup in low-generation or high-demand states.*

3.2 Preferences

Let household i's type be

$$\theta_i = (\rho_i, \lambda_i, \chi_i, \phi_i, \psi_i),$$

where:

- $\rho_i \geq 0$: aversion to bill volatility,
- $\lambda_i \geq 0$: sensitivity to outage burden,
- $\chi_i \geq 0$: valuation of lower emissions,
- $\phi_i \geq 0$: valuation of autonomy,
- $\psi_i \geq 0$: valuation of backup/insurance from staying connected.

Expected cost enters utility with coefficient normalised to one. The household's utility from bundle-contract pair (j, m) is

$$U_i(j,m) = -\mu_{ijm} - \frac{\rho_i}{2}\sigma_{jm}^2 - \lambda_i \mathbb{E}[L(X_{jm})] - \chi_i e_{jm} + \phi_i a_j + \psi_i b_j + \varepsilon_{ijm}, j \in \mathcal{J}^c, \tag{1}$$

and for the off-grid option,

$$U_i(O) = -\mu_{iO} - \frac{\rho_i}{2}\sigma_O^2 - \lambda_i \mathbb{E}[L(X_O)] - \chi_i e_O + \phi_i a_O + \varepsilon_{iO}, \tag{2}$$

since $b_O = 0$. Here ε_{ijm} is an idiosyncratic taste shock.

The household chooses

$$(j_i^*, m_i^*) \in \arg\max \left\{ \max_{j \in \mathcal{J}^c,\, m \in \mathcal{M}} U_i(j,m),\ U_i(O) \right\}. \tag{3}$$

The specification in (1)-(3) improves on a simple additive index in three ways. First, bill volatility enters through a certainty-equivalent term. Second, reliability enters nonlinearly through a convex outage-loss function. Third, the model explicitly separates autonomy from the option value of remaining grid-connected. This is the distinction that is highlighted in the empirical literature on "energy independence" (Australian Energy Market Operator, 2022).

3.3 Technology ordering

The model does not require a strict ranking of all bundles along all dimensions, but the following weak inequalities are natural:

$$a_O > a_E \geq a_B \geq a_S \geq a_G, \tag{4}$$

$$0 = b_O < b_G \leq b_S \leq b_B \leq b_E, \tag{5}$$

and for connected bundles,

$$\sigma_E^2 \leq \sigma_B^2 \leq \sigma_S^2 \leq \sigma_G^2, \mathbb{E}[L(X_E)] \leq \mathbb{E}[L(X_B)] \leq \mathbb{E}[L(X_S)] \leq \mathbb{E}[L(X_G)]. \tag{6}$$

The logic is as follows. Adding PV, storage, and flexible load generally improves hedging against price shocks and outages. But the off-grid bundle does not necessarily dominate connected battery bundles on reliability, precisely because it forgoes the grid as a fallback technology and therefore may require expensive overbuilding to cope with rare low-solar or prolonged high-demand episodes (Kleinebrahm et al., 2023).[6]

To capture the geography of network economics, let connected bundles include a location-specific connection burden $n_i \geq 0$:

$$\mu_{ijm} = \bar{\mu}_{jm} + F_m + n_i - r_{jm}^x - s_{jm}^f, j \in \mathcal{J}^c, \tag{7}$$

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[6] *See also Rocky Mountain Institute (2014), which emphasises that full grid defection generally requires costly overbuilding of local generation and storage to cover low-probability but high-cost states.*

where F_m is a fixed charge, r_{jm}^x is expected export remuneration, and s_{jm}^f is expected flexibility or orchestration compensation. For the off-grid option,

$$\mu_{iO} = \bar{\mu}_O. \tag{8}$$

Thus, higher fixed charges and higher location-specific network costs make connected bundles less attractive, while export and flexibility payments make them more attractive.

3.4 The platform problem

The centralised system is modelled as a platform that chooses the contract menu $\mathcal{M}$. Each contract specifies a vector of terms

$$m = (F_m, p_m, r_m^x, s_m^f, q_m),$$

where F_m is a fixed charge, p_m denotes volumetric or dynamic price terms, r_m^x export remuneration, s_m^f flexibility/VPP compensation, and q_m any additional quality, green, or reliability-related service dimension.

Let the household's maximum connected utility be

$$V_i^C(\mathcal{M}) = \max_{j \in \mathcal{J}^C,\, m \in \mathcal{M}} U_i(j, m), \tag{9}$$

and let off-grid utility be $V_i^O = U_i(O)$. Household i remains connected if and only if

$$V_i^C(\mathcal{M}) \geq V_i^O. \tag{10}$$

The platform chooses $\mathcal{M}$ to maximise

$$\Pi(\mathcal{M}) = \int_{\{i: V_i^C(\mathcal{M}) \geq V_i^O\}} \pi_i(\mathcal{M})\, dH(i) - K(\mathcal{M}), \tag{11}$$

where $H(i)$ is the distribution of household types, $\pi_i(\mathcal{M})$ is the platform's net return from retaining household i, and $K(\mathcal{M})$ is the cost of offering and administering a richer menu. Smart meters and digitalisation matter in this framework because they reduce the practical cost of offering differentiated contracts and make more complex menus feasible (Australian Energy Regulator, n.d.).

Equation (11) captures the trade-off facing the centralised system. A broader menu can retain more heterogeneous consumers, but it may also be more costly to design, communicate, meter, and administer.

3.5 Propositions

Proposition 1.

If $\mathcal{M}' \supseteq \mathcal{M}$, then for every household i,

$$V_i^C(\mathcal{M}') \geq V_i^C(\mathcal{M}). \tag{12}$$

Hence the set of households that choose off-grid under $\mathcal{M}'$ is a weak subset of the set of households that choose off-grid under $\mathcal{M}$.

Proof.

The maximisation problem in (9) is taken over a weakly larger feasible set when $\mathcal{M}' \supseteq \mathcal{M}$. Therefore, the household's maximum attainable connected utility cannot fall. If a household chose a connected option under $\mathcal{M}$, it can still choose that option under $\mathcal{M}'$. If a household chose off-grid under $\mathcal{M}$, the expanded menu may induce it to remain connected. Therefore off-grid choice weakly falls. □

This proposition formalises the idea that contract variety is itself a retention technology. A narrow menu induces welfare losses when households are heterogeneous. A broader menu weakly reduces such losses.

Proposition 2.

Suppose connected bundles take the cost form in (7). Then, for any household type i, $V_i^C(\mathcal{M})$ is weakly decreasing in the fixed charge F_m and in the location-specific network burden n_i. If there exist values of n_i such that $V_i^C(\mathcal{M}) > V_i^O$ for low n_i and $V_i^C(\mathcal{M}) < V_i^O$ for high n_i, then there exists a threshold n_i^* such that the household remains connected when $n_i < n_i^*$ and chooses off-grid when $n_i > n_i^*$.

Proof.

By (7), an increase in F_m or n_i raises expected cost one-for-one for all connected bundles and does not affect the off-grid alternative. Therefore, all connected utilities weakly fall, while off-grid utility is unchanged. If connected utility exceeds off-grid utility at low n_i but not at high n_i, continuity implies a threshold value n_i^*. □

This proposition generates the geography result: off-grid adoption should cluster in high-cost-to-serve areas, consistent with observed network-led stand-alone deployments – as indicated earlier.

Proposition 3.

Comparing B (grid + PV + battery) with S (grid + PV), household i prefers B to S if and only if

$$\mu_{iS} - \mu_{iB} + \frac{\rho_i}{2}(\sigma_S^2 - \sigma_B^2) + \lambda_i[\mathbb{E}[L(X_S)] - \mathbb{E}[L(X_B)]] + \chi_i(e_S - e_B) + \phi_i(a_B - a_S) + \psi_i(b_B - b_S) \geq 0 \tag{13}$$

A reduction in export remuneration for PV-only systems raises the relative attractiveness of B compared with S, provided the battery allows sufficiently more self-consumption and therefore reduces exposure to weakened export economics.

Proof.

Subtract $U_i(S, m_S)$ from $U_i(B, m_B)$ using (1). Rearranging yields condition (13). A fall in export remuneration raises μ_{iS} relative to μ_{iB} if the battery bundle depends less on exports, thereby making the left-hand side larger. □

This proposition matters because it shows why policy changes need not produce immediate full defection. They may instead induce portfolio reconfiguration from S to B, which is exactly the pattern described in the empirical discussion.[7]

3.6 Main implications of the model

The model yields four broad predictions. First, widespread DER adoption with continued connection is the natural equilibrium when ψ_i, the value of backup, is substantial for many households and fixed charges are not too high. Second, batteries are especially attractive because they improve hedging against bill volatility and outage risk while preserving the insurance value of the grid. Third, full off-grid choice is concentrated among households with high autonomy value, low relative valuation of grid backup, and/or high location-specific network costs. Fourth, the centralised system can retain more households by broadening the contract menu rather than relying on uniform pricing alone. Smart meters matter not only because they enable dynamic pricing, but because they expand the feasible set of differentiated contracts more generally.[8] In short, the relevant long-run competition is not simply 'grid versus no grid'. It is competition between alternative bundles of self-supply, insurance, flexibility, and governance.

4 Parameterising the model and interpreting equilibrium

Section 4 maps the empirical evidence into the primitives of the model. This includes not only household-side preference parameters, but also platform-side design variables such as menu breadth, fixed charges, export remuneration, and flexibility payments. The transition path, therefore, depends on both household heterogeneity and the extent to which the centralised system adapts its offering in response to improving outside options.

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[7] *U.S. evidence from California shows rising battery attachment rates for new residential solar installations after export compensation weakened (U.S. Energy Information Administration, 2024).*

[8] *Australian Energy Regulator guidance emphasises that the rollout is intended to support broader tariff choice and improved access to meter data (Australian Energy Regulator, n.d.).*

4.1 Household-side parameters and segments

The first step is to map the empirical evidence into the parameters $(\rho_i, \lambda_i, \chi_i, \phi_i, \psi_i)$. The expected-cost term remains the dominant margin for the median household. The strongest broad-based empirical signal is that financial motives are the main driver of rooftop solar adoption. This implies that, for a large share of households, expected annual private cost μ_{ijm} remains the first-order screening device: other motives matter, but usually only once the private economics are good enough (CSIRO, 2019).

The volatility-aversion parameter ρ_i captures willingness to pay for bill stability. The Deloitte/ Australian Energy Market Operator evidence on consumers' willingness to pay to reduce bills provides a natural anchor for this parameter, while the persistence of flat-price contracting in Finland offers an external validity check that a substantial segment values stable prices more than exposure to dynamic tariffs with lower expected cost but greater variance (Deloitte, 2023; Numminen et al., 2025).

The reliability parameter λ_i should be interpreted jointly with the convex outage-loss function $L(\cdot)$. The relevant empirical fact is not just that households dislike outages, but that marginal disutility is highly nonlinear. Australian Energy Regulator's VCR estimates indicate that severe interruptions are extremely costly in monetised terms, whereas many households show little willingness to pay to avoid small baseline outages. This supports a model in which outage costs are highly convex rather than linear (Australian Energy Regulator, 2024).

The emissions parameter χ_i captures the value households place on lower carbon footprints. The evidence suggests that this motive is meaningful for a large minority, and sometimes strong enough to justify adoption even when strict private financial payback is relatively weak (Ma et al., 2015). The autonomy parameter ϕ_i captures the value attached to independence, control, and reduced exposure to centralised tariff and governance decisions. The evidence indicates that this parameter is low for many households, but exhibits a long right tail. In broad rooftop-solar surveys, only a small minority cite grid independence as a major motive; among battery-oriented early adopters, however, stated aspirations for eventual disconnection are much stronger (CSIRO, 2019; Agnew and Dargusch, 2017).

The backup parameter ψ_i captures the insurance value of remaining connected. This parameter is central because it stabilises hybrid equilibria. Even households with substantial autonomy motives may still prefer a connected bundle when the grid retains significant option value in rare but severe states. The literature on self-sufficiency and off-grid economics supports this interpretation (Kleinebrahm et al., 2023).[9] A useful way to summarise the distribution of these parameters is through five segments, which are explained in Table 1.

Table 1. Five customer segments

Segment	Description
Bill minimisers	This is the plurality segment. Expected private cost is the dominant margin, while volatility, reliability, carbon, and autonomy matter secondarily. This segment drives mass PV uptake when private returns are strong (CSIRO, 2019).
Bill insurers	This segment has a relatively high ρ_i. It values flat tariffs, hedging, and technologies that reduce bill uncertainty. It may dislike complex dynamic pricing unless the gains are large and transparent (Deloitte, 2023; Numminen et al., 2025).
Resilience seekers	This segment has high effective outage sensitivity because λ_i is important and $L(\cdot)$ is sharply convex. It is more likely to adopt batteries for backup, but often remains connected because ψ_i is also high (Australian Energy Regulator, 2024).
Decarbonisers	This values-driven minority has relatively high χ_i. It may adopt PV, batteries, or EVs even when strict private payback is somewhat weaker than for bill-minimising households (Ma et al., 2015).
Autonomy seekers	This is the most relevant group for off-grid dynamics. It has high ϕ_i, and may be willing to pay substantial premia for control and self-sufficiency, especially where distrust, perceived unfairness, or dissatisfaction with centralised arrangements is strong (Australian Energy Market Operator, 2022; Agnew and Dargusch, 2017; CSIRO, 2019).

Although the model does not estimate segment shares, it does permit an illustrative calibration of how the distribution of dominant-motive households may evolve if current technology, metering, and policy trajectories persist. Under such a scenario, bill minimisers are likely to remain the plurality segment throughout the transition, but their share should gradually decline as storage, electrification, and contract differentiation make resilience, autonomy, and environmental motives more behaviourally consequential. A plausible range is that bill minimisers account for roughly 40–45 per cent of households around 2030, falling to about 25–35 per cent by 2050. Bill insurers are likely to remain relatively stable, at around 20–25 per cent over most of the period, reflecting persistent demand for bill stability even in a more digital and flexible retail environment. Resilience seekers may rise from approximately 10–15 per cent in 2030 to around 18–23 per

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[9] *See further details in footnote 6.*

cent by 2050 as batteries, outage salience, and backup-oriented value propositions become more prominent. Decarbonisers are likely to remain a sizeable minority, perhaps around 15–20 per cent throughout, with at most a modest upward drift. Autonomy seekers should remain the smallest segment, but could grow from roughly 5–10 per cent in 2030 to around 10–15 per cent by 2050, especially if dissatisfaction with centralised arrangements persists and self-supply technologies continue to improve. These figures should be interpreted as scenario-based dominant-segment shares rather than forecasts, but they summarise the most likely directional shifts implied by the model and the empirical evidence.

4.2 Platform-side design variables

The second step is to map institutional and regulatory developments into the platform's choice variables. The first such variable is the breadth of the contract menu, $\mathcal{M}$. A richer menu permits better matching between household heterogeneity and offered contracts. In the model, menu breadth matters because it raises $V_i^C(\mathcal{M})$, the maximum connected utility available to a household. Proposition 1 therefore implies that broader menus weakly reduce disconnection. Smart-meter rollout is important in this framework because it expands the feasible menu and lowers the cost of implementing differentiated contracts. The second variable is the fixed charge F_m. A higher fixed charge raises the cost of all connected bundles and therefore weakly increases pressure toward disconnection, particularly for households with high ϕ_i or high n_i. Proposition 2 shows that fixed charges matter most for households already near the connected/off-grid margin. The third variable is export remuneration, r_m^x. When export terms become less favourable, the relative attractiveness of PV-only configurations falls. Proposition 3 predicts that such changes may shift households from S to B rather than directly from connected to off-grid, because batteries restore self-consumption and hedge against weakened export compensation (U.S. Energy Information Administration, 2024). The fourth variable is flexibility or orchestration compensation, s_m^f. This includes VPP payments, demand response payments, and other forms of compensation for making household flexibility available to the wider system. Such payments raise connected utility, particularly for households with batteries or EVs. But they may be less effective for autonomy seekers if these arrangements are perceived as intrusive or as a re-centralisation of control. A fifth variable is the availability of green and reliability product differentiation. The more the platform can tailor contracts to preferences over emissions and resilience, the lower the welfare loss from forcing heterogeneous consumers into a narrow contract menu.

This platform-side interpretation is important because it turns transition outcomes into equilibrium objects. Household technology costs matter, but so does the way the centralised system chooses to respond.

4.3 Equilibrium implications

Taken together, the parameterisation of household heterogeneity and platform instruments yields three main equilibrium implications. First, the most likely short- to medium-run adjustment margin is not full defection, but portfolio reconfiguration within continued grid connection. When technology costs fall or export compensation weakens, households often move from $G$to S, and from $S$to B, rather than to O. The reason is straightforward: batteries reduce bill volatility and outage exposure while preserving the option value of grid backup (Kleinebrahm et al., 2023; U.S. Energy Information Administration, 2024; Rocky Mountain Institute, 2014).

Second, contract innovation is a retention mechanism. If the platform broadens $\mathcal{M}$, more household types can be profitably or efficiently retained. This is especially relevant in a smart-meter world, where contract variety becomes technically feasible on a much larger scale (Australian Energy Regulator, n.d.). In the language of the model, smart meters do not merely enable dynamic pricing; they expand the set of feasible ways to match heterogeneous preferences.

Third, off-grid outcomes should remain geographically concentrated. Proposition 2 implies that higher location-specific network burdens n_i produce local thresholds at which off-grid or standalone solutions dominate conventional connection. This is consistent with current practice, where the most visible deployment of standalone systems has occurred in remote or high-cost-to-serve areas rather than as a mass urban phenomenon.[10]

The combined implication is that the transition depends on two interacting forces: improving household outside options, and the platform's ability to adapt its menu fast enough and credibly enough to retain heterogeneous consumers.

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[10] *See footnote 4.*

4.4 Transition path and likely end state

The transition path described below can also be interpreted as a gradual reweighting of dominant household motives, with the distribution shifting away from bill minimisers alone and toward a broader mix of bill insurers, resilience seekers, decarbonisers, and, at the margin, autonomy seekers.

The model also helps interpret the speed and likely endpoint of the transition. A useful operational definition of "completion" is that the transition is complete when: (i) smart-meter enablement is near-universal, (ii) DER adoption is close to saturation for technically suitable households, and (iii) the remaining relationship between households and the grid is structurally stable, meaning that tariffs and products have adapted to a two-way, high-electrification system. (Australian Energy Market Operator, 2024). Under this definition, the late 2020s to mid-2030s are likely to be characterised by rapid expansion of the feasible menu $\mathcal{M}$, driven by compulsory smart-meter rollout, falling battery costs, and rising DER penetration (Australian Energy Market Operator, 2024). The dominant adjustment in this phase should be movement toward connected DER bundles, especially S and B, together with growing importance of flexibility payments and differentiated tariffs.

The mid-2030s to 2050 period is more plausibly interpreted as a phase of consolidation into a high-DER hybrid equilibrium. In that equilibrium, the grid remains central, but its role shifts away from being primarily a one-way energy delivery system and toward being a platform for balancing, insurance, flexibility, and trade. Households self-supply a larger share of energy and services, but many continue to value the grid precisely because ψ_i, the insurance value of connection, remains positive for a large part of the population (Rocky Mountain Institute, 2014; Kleinebrahm et al., 2023; Australian Energy Market Operator, 2024).

The model therefore puts very different probabilities on the candidate end states. The most likely equilibrium is that the grid remains available in most populated areas, but in a transformed role. This is the outcome most consistent with high heterogeneity, strong backup value, smart-meter-enabled contract variety, and continuing DER growth (Australian Energy Market Operator, 2024).

A second likely outcome is selective replacement of conventional grid supply in remote or high-cost areas. Proposition 2 makes clear why: sufficiently high n_i can push households or networks past the threshold where standalone solutions dominate poles-and-wires supply. This is not a contradiction of the hybrid equilibrium, but one that acknowledges its geographically differentiated components.

The least likely outcome is complete disappearance of the centralised grid. That would require autonomy values ϕ_i to dominate backup values ψ_i for a very large share of households, while technology costs and reliability constraints simultaneously fall enough to remove the insurance advantage of continued connection. The empirical literature cited earlier does not support that configuration (Rocky Mountain Institute, 2014; Kleinebrahm et al., 2023).

The broad conclusion is therefore not that centralisation automatically causes defection. Rather, centralisation that fails to adapt increases the outside-option value of partial or full exit. A centralised system that adapts by expanding menu variety and preserving a credible "backup bargain" can remain the dominant platform even in a world of very high household self-supply.

5 Conclusion

This paper has analysed the evolving relationship between households and the electricity grid in an environment characterised by widespread diffusion of distributed energy resources, growing heterogeneity in household preferences, and an expanding menu of technologically feasible retail and network arrangements. The central result is that the relevant long-run margin is not well described as a binary choice between continued grid reliance and complete disconnection. Rather, households choose among a set of connected and disconnected energy-service bundles, while the centralised system adapts by offering a menu of contracts that can either retain or repel different household types. Once this interaction is modelled explicitly, the future of grid connection depends not only on technology costs, but also on contract design, reliability value, and the geographic cost of maintaining connection.

An evidence-consistent ordering of household preferences emerges from the literature reviewed in Sections 2 and 4. For the median household, expected bill savings appear to be the dominant driver of adoption. Reliability is also highly valued, but mainly for severe outage states rather than for marginal improvements around already high baseline reliability. Bill stability is important for a substantial share of households, especially where exposure to volatile tariffs is salient. Environmental motives are meaningful for a large minority, while autonomy and self-sufficiency exhibit a long right tail: they are weak for many households, but strong enough for a smaller segment to justify materially different choices. Most importantly, the backup value of remaining connected appears to remain positive for a large part of the population, which helps explain why full disconnection remains a niche outcome even where self-supply becomes increasingly attractive (CSIRO, 2019; Deloitte, 2023; Australian Energy Regulator, 2024; Ma et al., 2015; Agnew and Dargusch, 2017; Rocky Mountain Institute, 2014; Kleinebrahm et al., 2023).

The empirical signature of the transition is therefore dispersion rather than convergence. Financial and risk-related motives anchor the centre of the distribution, while autonomy- and values-driven motives create important tails. This heterogeneity matters because it implies that a uniform tariff or product environment will inevitably fit some households poorly. In the framework developed here, that mismatch is precisely what creates scope for disconnection at the margin. Conversely, contract differentiation operates as a retention technology: when the platform can offer a broader set of tariffs, export arrangements, and flexibility contracts, it can accommodate a wider range of household preferences without requiring households to leave the system altogether.

This retention mechanism should not be interpreted only in static terms. Contract differentiation also has a dynamic and strategic dimension. Early contract innovation may reduce the risk of inefficient disconnection by retaining households whose demand for autonomy, bill stability, resilience, or flexibility compensation cannot be accommodated under legacy tariff structures, but for whom grid connection still has positive option value. Conversely, delayed adaptation may make disconnection outcomes partly path dependent. Once households have invested in self-supply technologies, adjusted consumption routines, and formed expectations around greater autonomy from the centralised system, the outside option of partial or full exit may become more durable. Contract design therefore affects not only the current connected/off-grid margin, but also the transition path through which household-grid relationships become locked in.

The model also suggests a plausible sequencing of the transition. By around 2030, smart-meter deployment and associated reforms are likely to have expanded the feasible set of differentiated household contracts substantially, while continued declines in storage costs and further diffusion of electrified end uses will increase the attractiveness of connected photovoltaic and storage bundles. Recent Australian evidence on electric-vehicle uptake is consistent with that broader electrification trajectory and suggests that transport electrification is likely to strengthen the household flexibility margin over time (Electric Vehicle Council, 2026). In the following decade, the most likely adjustment is not mass disconnection, but deeper reallocation within continued connection: more households move from grid-only supply to grid-plus-generation and then to grid-plus-generation-plus-storage, while participation in flexibility arrangements becomes more common where trust, simplicity, and compensation are sufficient. Under this interpretation, the most defensible medium-run endpoint is a mature equilibrium in which decentralised generation is widespread, but the grid remains central as a provider of balancing, insurance, and trading services rather than merely a one-way delivery system (Australian Energy Market Operator, 2024; International Energy Agency, 2024).

The model further implies that end states are likely to differ systematically across locations. In dense networks, the dominant outcome is continued connection under increasingly differentiated contracts. In remote or high-cost-to-serve areas, by contrast, stand-alone or off-grid outcomes become more plausible because the network cost of connection is intrinsically higher and the threshold for efficient replacement is more readily crossed. This geographic differentiation is consistent both with observed stand-alone deployment and with the comparative statics of the model. It follows that the future electricity system is likely to combine an enduring central platform in most populated areas with selective withdrawal of conventional grid supply where stand-alone service is more efficient. What is least consistent with the current evidence is the proposition that the centralised grid disappears as a dominant institution across dense networks. Such an outcome would require autonomy motives to dominate reliability and insurance value for a very large share of households, while technology and institutional change simultaneously eliminated the residual value of connection; neither the empirical literature nor current deployment patterns support that conclusion (Kleinebrahm et al., 2023).

The policy implication is not that centralised systems should resist decentralisation, but that they must adapt to it. Smart meters, export arrangements, and flexibility payments expand the feasible set of contracts, but they also raise the stakes of complexity, trust, and distributional design. Recent Australian evidence further suggests that willingness to participate in battery orchestration and virtual power plant arrangements depends critically on perceived fairness, control, and trust (Roberts et al., 2023). Blunt cost-recovery responses, especially those that erode the value proposition of connection for marginal households, may accelerate inefficient exit. By contrast, a carefully designed contract menu can retain heterogeneous households while drawing on their distributed resources for system value. The broader lesson is that the long-run viability of the grid depends less on preserving legacy tariff structures than on preserving a credible and valuable role for connection itself.

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