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Thin markets, thick subsidies: local competition and the incidence of heat pump grants

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Abstract
We study how local supply shapes the incidence and quantity response of clean-technology subsidies. In October 2023, the UK government increased the grant for air-source heat pumps from £5,000 to £7,500 in England and Wales, while Scotland left its policy unchanged. Using 260,000 certified heat pump installation records in a difference-in-differences comparison of Northern England with Scotland, we find that the grant increase raised monthly installations by 24%, adding roughly 7,200 units over 20 post-reform months. Reported pre-grant installation costs fell by about £830, so household out-of-pocket payments declined by more than the £2,500 grant increase. The quantity expansion and the cost reduction were larger in local areas with more competition prior to the policy. Supply adjusted through local installer entry, wider geographic reach among existing installers, and a shift toward smaller, higher-efficiency heat pumps. While changes in heat pump size and model mix explain roughly half of the unconditional cost drop, within-installer-and-model price cuts account for a quarter of the average decline and half of the additional price drop in more competitive markets. Combining these estimates with engineering-based carbon abatement yields a marginal value of public funds of 2.1, rising to 2.5 in markets one standard deviation above mean competition.

Keywords: subsidy incidence; pass-through; imperfect competition; technology adoption; heat pumps

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1 Introduction

Heating accounts for roughly 10% of global and 20% of the United Kingdom's CO_2 emissions (HM Government, 2021; IEA, 2022), and 72% of European homes still rely on fossil-fuel heating (European Commission, 2024). Although electric heat pumps are three to four times more thermally efficient than gas boilers (IEA, 2022), global deployment stands at about a quarter of the pace required to meet 2030 net-zero targets (Rosenow et al., 2022). The UK illustrates the bottleneck: against an official target of 600,000 installations per year by 2028, roughly 60,000 units were installed in 2025 (Department for Energy Security and Net Zero, 2026). Industry assessments point to installer capacity as a primary constraint, with around 3,000 certified heat pump installers operating nationwide compared with an estimated 37,000 required (Cretu et al., 2022). This paper examines how a large consumer subsidy performs when local installer markets are thin.

Governments routinely use purchase subsidies to encourage the adoption of durable goods that carry environmental externalities or suffer from household underinvestment due to credit constraints, imperfect information, or principal-agent frictions (Allcott & Greenstone, 2012; Gerarden et al., 2017; Gillingham & Palmer, 2014). For residential energy technologies, however, the good purchased is a bundle of manufactured equipment and local installation services, including site assessment, hydronic system design, physical installation, and certification. Because qualified installers are unevenly distributed across space and face capacity and travel constraints, a uniform national subsidy may yield markedly different quantity and price responses across local markets.

A large empirical literature estimates consumer take-up and pass-through of subsidies for energy-efficient appliances, weatherization, rooftop solar, and electric vehicles (Davis et al., 2014; Fowlie et al., 2018; Gillingham & Tsvetanov, 2019; Muehlegger & Rapson, 2022; Springel, 2021), while a parallel literature examines how market power shapes tax and subsidy incidence (Benzarti & Carloni, 2019; Gulati et al., 2017; Pless & van Benthem, 2019; Sallee, 2011). Recent work on residential electrification studies the determinants of heat pump adoption and its distributional implications (S. Anderson & Kirkpatrick, 2024; Davis, 2024, 2025), but the role of local installer competition has received little direct empirical attention. Standard oligopoly theory predicts that, holding marginal-cost curvature fixed, an outward demand shift translates more into output and less into markups where local supply is less concentrated (S. P. Anderson et al., 2001; Bresnahan & Reiss, 1991; Weyl & Fabinger, 2013). If the demand expansion is large enough to cover fixed costs of local market entry, it can also draw in additional suppliers and lower pre-subsidy prices.

We test these predictions using a discrete increase in the Boiler Upgrade Scheme (BUS), the primary capital grant for low-carbon heating in England and Wales (Ofgem, 2023; UK Government, 2022). Similar capital grants for heat pumps are used in 22 European countries (European Heat Pump Association, 2025) and the US, Canada, China, Japan, and Korea (International Energy Agency, 2026). The UK BUS scheme is among the most generous ones. Under the BUS, accredited installers apply for fixed-value vouchers on behalf of households and deduct the grant from the

installation invoice. On 23 October 2023, the voucher for air-source heat pumps (ASHPs) rose from £5,000 to £7,500, and the voucher for ground-source heat pumps rose from £6,000 to £7,500. Because heating policy is devolved, the BUS applies only to England and Wales, whereas Scotland operates separate clean-heating schemes whose parameters did not change in October 2023 (Home Energy Scotland, 2025). We exploit this institutional boundary in a difference-in-differences design comparing Northern England with Scotland over a 57-month window spanning 36 months before to 20 months after the reform, ending in June 2025.

Our analysis uses administrative records from the Microgeneration Certification Scheme (MCS), which covers virtually all subsidy-eligible domestic installations (Microgeneration Certification Scheme, 2025). Each record reports the commissioning date, technology, installation postcode, installer identifier, technical system ratings, and, for a large subset of observations, the gross installation cost prior to deducting the BUS voucher. We map installation postcodes to Lower-layer Super Output Areas (LSOAs) and Travel-to-Work Areas (TTWAs) and link installer identifiers to the MCS installer registry to track firm headquarters and certification spells.[1] We focus on ASHPs, which represent 93% of heat pump installations in our sample and experienced the full £2,500 grant increase. Our estimates capture responses in completed installations and reported pre-grant invoices, because the administrative data record completed commissionings rather than quote requests, voucher applications, waiting times, or household demographics.

We next examine how the policy response varies with pre-existing local market structure. For each TTWA, we compute the inverse Herfindahl–Hirschman index (HHI^{-1}) of installer market shares using pre-policy installations from 2015 to 2021, standardise it across TTWAs, and interact it with the England-by-post treatment indicator. Conditional on LSOA fixed effects, calendar year-month fixed effects, rural-by-month fixed effects, and interactions with baseline local heat pump adoption, this triple-difference specification estimates how the October 2023 treatment effect varies across local installer markets of differing initial concentration. Because pre-policy market structure is not randomly assigned, we interpret these interaction coefficients as systematic treatment-effect heterogeneity rather than the causal effect of an exogenous change in concentration.

We document five main sets of results. First, the grant increase substantially raised heat pump adoption. In our baseline Poisson pseudo-maximum-likelihood (PPML) specification, monthly ASHP installations in Northern England increased by 24% relative to Scotland following the October 2023 reform (Table 1, column 1). Event-study estimates show no differential pre-trends and a sustained post-reform increase across all 20 observed months, amounting to roughly 7,200 additional installations in the treated English sample. Second, this quantity response is significantly larger

[1]Under the 2011 Census geography, England has 32,844 LSOAs (1,000–3,000 residents) and Wales has 1,909, while Scotland has 6,976 Data Zones (500–1,000 residents). The ONS Postcode Directory harmonises these into a single field, and we refer to all units as LSOAs. Because Scottish Data Zones are roughly half the population size of English LSOAs, installation counts are not comparable in levels across the border. Our specifications include LSOA fixed effects and identify off within-area changes across 12,992 areas. TTWAs (228 across the UK in 2011) are commuting-based local labour markets constructed so that at least 75% of resident workers work within the area and 75% of local workers live within it.

in more competitive local installer markets: a one-standard-deviation increase in pre-policy inverse HHI is associated with an additional 0.125 log-point increase in monthly installations, and TTWAs in the top quartile of pre-policy competition exhibit a 0.289 log-point larger response.

Third, reported pre-grant installation costs fall by £827 at the reference competition level in our unconditional specification (Table 2, column 4). Because the MCS cost variable records the gross invoice before subtracting the voucher (see Appendix A.1), a fall in reported cost implies that household out-of-pocket expenditure declined by the £2,500 grant increment plus £827, corresponding to an invoice-based pass-through rate of 1.33. Moreover, the cost reduction is steeper in more competitive markets, falling by an additional £333 per standard deviation of pre-policy competition.

Fourth, we investigate the mechanisms behind this cost decline using installer-activity measures and an exact nested-regression decomposition. Following the grant increase, the number of active installers in an English LSOA-month rises by 19%, the count of active installers headquartered outside the local TTWA rises by 45%, and the average distance between an installation and the installer's headquarters increases by about 30% (18 km). At the same time, installed systems become smaller by 0.57 kW within installer and have higher rated seasonal coefficients of performance (SCOP). Decomposing the £827 unconditional cost drop into heat pump capacity, model-and-installer composition, and within-installer-by-model components reveals that smaller heat pump system sizes account for £299 and shifts across models and installers account for £321. Even when holding fixed the installer, exact heat pump model, and system capacity, the pre-grant price falls by £206 on average and by an additional £169 per standard deviation of local competition.

The within-pair price drop and the surge in cross-TTWA installer entry point to a pro-competitive market-size effect, while part of the unconditional invoice reduction reflects a compositional shift toward smaller dwellings or cheaper heat pump units (and potential reporting noise if some installers mistakenly entered net-of-grant figures). As formalised in a simple Cournot free-entry model in Appendix K,[2] a large subsidy expands local demand enough for outside installers to cover the fixed costs of entering a local market, intensifying competition and lowering gross prices. This mechanism parallels evidence from pharmaceuticals and solar manufacturing showing that policy-induced market expansion stimulates firm entry and cost-reducing innovation (Acemoglu & Linn, 2004; Blume-Kohout & Sood, 2013; Finkelstein, 2004; Gerarden, 2023; Kremer et al., 2020), but operates here at the level of local service markets through geographic range extension and local competition. Correlating pre-policy TTWA competition with local supply and demand characteristics via post-Lasso regressions further indicates that local competition is primarily associated with supply-side capabilities: local plumber wages, construction self-employment, and proximity to heat pump training centres.

Fifth, we combine our behavioural estimates with installation-specific engineering calculations of displaced gas and electricity consumption to evaluate the marginal value of public funds (MVPF) of the £2,500 grant increment (Hahn et al., 2024; Hendren & Sprung-Keyser, 2020). Using MCS

[2] An interactive version of the model is available at https://mondpanther.github.io/subsidies_competition/.

rated efficiencies and design heat demand, the grant increase yields a baseline MVPF of 2.12 and a public cost of £188 per tonne of CO_2e abated, below the UK government's £265 appraisal carbon value. Because induced adoption is higher in thicker markets, the MVPF rises from 1.92 at mean competition to 2.51 in markets one standard deviation above the mean, lowering the government cost per tonne from £229 to £139. We emphasise, however, that engineering ratings overstate in-situ energy savings: substituting metered heat pump consumption estimates from Bernard et al. (2024) halves lifetime abatement, reducing the baseline MVPF to 1.46 and raising the fiscal cost to £416 per tonne.

Section 2 describes the institutional setting and theoretical framework. Section 3 details the MCS data and local competition measures. Section 4 sets out the empirical strategy. Section 5 presents the main quantity and price estimates, mechanism tests, price decomposition, and correlates of local competition. Section 6 reports the welfare and cost-effectiveness analysis, and Section 7 concludes.

2 Institutional background and economic framework

2.1 Policy and market environment

The Boiler Upgrade Scheme (BUS) is the principal capital grant programme for low-carbon heating in existing domestic and small non-domestic buildings in England and Wales. Administered by Ofgem under statutory regulations enacted in 2022, the scheme provides fixed-value vouchers redeemed upon system commissioning (Ofgem, 2023; UK Government, 2022). The application process is installer-led: an accredited installer applies for the voucher on the homeowner's behalf, completes the installation, claims the grant, and deducts the voucher amount from the customer's final invoice.

Our empirical analysis exploits the discrete increase in BUS voucher values that took effect on Monday, 23 October 2023. Prior to that date, the scheme offered £5,000 for air-source heat pumps (ASHPs) and £6,000 for ground-source heat pumps (GSHPs). From 23 October 2023 onward, the grant rose to £7,500 for both technologies, while the grant for biomass boilers remained unchanged at £5,000.

To qualify for a BUS voucher, both the installer and the heat pump unit must be certified under the Microgeneration Certification Scheme (MCS) or an equivalent body, and the system must have a thermal capacity not exceeding 45 kWth (Microgeneration Certification Scheme, 2025; Ofgem, 2023), which restricts the programme to residential and small commercial properties. Because MCS certification is mandatory for subsidy eligibility, MCS commissioning records capture the universe of grant-supported installations alongside self-funded certified systems. The administrative records do not, however, report voucher application dates, customer quote dates, waiting times, or the net-of-grant payment made by the household.

Devolution provides a natural comparison group. The BUS operates only in England and Wales, whereas the Scottish Government runs the separate Home Energy Scotland Grant and Loan scheme

(Home Energy Scotland, 2025). Although the Scottish programme offers comparable support, providing a grant of up to £7,500 for domestic heat pumps paired with an optional interest-free loan, its eligibility rules and administration are independent of Ofgem, and its subsidy levels did not change in October 2023. We therefore use Scotland as the untreated comparison group for Northern England in our difference-in-differences framework.

Residential heat pump adoption in the UK also faces an operating-cost hurdle due to high retail electricity prices relative to natural gas. At prevailing domestic tariffs, a heat pump can be as expensive or more expensive to run than a condensing gas boiler despite its much higher thermal efficiency (Appendix Figure G.3). The BUS grant offsets the substantial upfront capital cost difference between a heat pump and a replacement gas boiler, even though ongoing fuel-price ratios remain a headwind to demand.

On the supply side, domestic heat pump installation is a locally bundled service. Unlike a drop-in gas boiler replacement, fitting a heat pump requires a room-by-room heat-loss assessment, hydraulic system design, potential upgrades to radiators and hot-water cylinders, physical unit installation, and post-commissioning support (Ofgem, 2023). Because these tasks are labour-intensive and sensitive to travel time, installers compete primarily within local geographic markets. When a subsidy increase shifts local demand outward, the market can clear through higher installation volumes, longer lead times, or higher installer markups. We examine the quantity response using monthly LSOA installation counts and the price response using the gross installation cost reported in the MCS records. Because the reported cost field includes the value of the BUS voucher as well as any ancillary emitter or cylinder upgrades bundled into the contract, we trim extreme cost outliers and explicitly account for changes in system characteristics when interpreting price movements.

2.2 Theoretical framework: subsidy incidence and local competition

To guide the empirical analysis, we set out a standard oligopoly incidence framework with local capacity constraints (S. P. Anderson et al., 2001; Pless & van Benthem, 2019; Weyl & Fabinger, 2013). Consider a local market m in which Q_m heat pump installations are completed per month at a gross pre-subsidy price p_m. A per-installation grant s lowers the net price paid by the household to $p_m - s$, yielding reduced-form local demand

$$Q_m = D_m(p_m - s), \quad D'_m(\cdot) < 0, \tag{1}$$

where $D_m(\cdot)$ reflects local housing stock suitability, climate, and household preferences. The October 2023 BUS reform represents a discrete increase $\Delta s > 0$ in England.

Suppose local installers compete in quantities and face upward-sloping marginal costs $mc_{jm}(q_{jm})$ arising from technician scheduling, local labour scarcity, or travel distance. With inverse demand

$p_m = P_m(Q_m; s)$, each active installer j chooses output q_{jm} to satisfy the first-order condition

$$P_m(Q_m; s) + q_{jm} \frac{\partial P_m(Q_m; s)}{\partial Q_m} = mc_{jm}(q_{jm}). \tag{2}$$

Multiplying (2) by installer j's market share $\omega_{jm} \equiv q_{jm}/Q_m$ and summing across active installers yields the aggregate pricing relation

$$P_m(Q_m; s) + Q_m \frac{\partial P_m(Q_m; s)}{\partial Q_m} \underbrace{\sum_j \omega_{jm}^2}_{\mathrm{HHI}_m} = \sum_j \omega_{jm}\, mc_{jm}(q_{jm}). \tag{3}$$

The Herfindahl–Hirschman index HHI_m summarises the oligopolistic wedge between the gross price and share-weighted marginal cost. Its reciprocal, the inverse HHI,

$$\mathrm{HHI}_m^{-1} \equiv \left(\sum_j \omega_{jm}^2 \right)^{-1}, \tag{4}$$

represents the effective number of symmetric competitors in market m.

In equation (3), a higher grant s shifts inverse demand upward. Holding marginal-cost curvature fixed, a more concentrated market (higher HHI_m) absorbs a larger share of the demand shift into markups and a smaller share into equilibrium output $\partial Q_m/\partial s$. A linear Cournot benchmark with N_m symmetric installers, constant marginal cost c_m, and inverse demand $P_m(Q_m; s) = a_m + s - bQ_m$ makes this clear:

$$Q_m(s) = \frac{N_m}{N_m + 1} \cdot \frac{a_m + s - c_m}{b}, \quad \frac{\partial Q_m}{\partial s} = \frac{N_m}{N_m + 1} \cdot \frac{1}{b}. \tag{5}$$

Here the quantity response $\partial Q_m/\partial s$ increases strictly with N_m. When installer shares are asymmetric, HHI_m^{-1} serves as the empirical counterpart to N_m.

Holding the number of active installers fixed, the static model in (5) also implies $\partial p_m/\partial s = 1/(N_m + 1) > 0$: the gross invoice price rises with the subsidy, and household pass-through $N_m/(N_m + 1)$ is less than one. In Appendix K, we extend this linear Cournot setup to allow free entry subject to a fixed market-entry cost. When a discrete subsidy increase expands local market revenue enough to draw in an additional installer, the resulting increase in competition causes the gross price p_m to fall discretely at the entry threshold, generating pass-through greater than one.

In our empirical specifications, we construct HHI_m^{-1} from pre-policy installation shares in each TTWA and standardise it into a competition index A_m. Because A_m is predetermined but potentially correlated with unobserved local demand or cost conditions, our interacted difference-in-differences regressions identify how the causal effect of the BUS grant increase varies with initial market structure, rather than the causal effect of exogenous variation in A_m.

3 Data

3.1 Administrative records and geographic mapping

Our primary data come from the Microgeneration Certification Scheme (MCS) installations database. Each observation represents a commissioned heat pump system and records the commissioning date, technology category (air-source, ground-source, or water-source), installation postcode, accredited installer identifier and company name, installed thermal capacity (kW), rated seasonal coefficient of performance (SCOP), design flow temperature, estimated annual space- and water-heating demand (kWh), and, for a subset of records, the total contract cost. Appendix Figure G.1 displays a representative installation record. As noted in Section 2, the MCS extract does not contain household socio-economic covariates, dwelling characteristics, pre-existing heating fuel, quote dates, or confirmation of BUS voucher redemption.

We map each installation postcode to its 2011 Lower-layer Super Output Area (LSOA, or Scottish Data Zone), Travel-to-Work Area (TTWA), rural–urban classification, country, and postcode-centroid coordinates using the Office for National Statistics (ONS) Postcode Directory. TTWAs capture self-contained commuting zones and serve as our definition of local installer markets, while LSOAs form the fine geographic grid for our panel regressions. Approximately 1.4% of MCS records lack a valid mappable postcode and are excluded from the spatial panels.

We merge the installation records with the MCS installer registry, which provides each accredited firm's registered headquarters postcode (mapped to coordinates and TTWAs) and certification start and end dates. For 19 installer identifiers that were recycled across distinct companies over time, we match on company name rather than the numeric identifier (Appendix A.1).

3.2 Outcomes, time indexing, and analysis samples

We aggregate the daily commissioning records to calendar year-months τ, defining event time rel_τ as the number of calendar months relative to October 2023 (so $\text{rel}_\tau = 0$ in October 2023, when the grant increase took effect on the 23rd). Our primary quantity outcome, $Y_{i\tau}^{AHP}$, is the monthly count of commissioned ASHP installations in LSOA i and month τ.[3] We focus on ASHPs because they represent 93% of heat pump installations in our sample and received the larger £2,500 grant increase, whereas non-air-source counts are too sparse at the LSOA-month level for precise estimation.

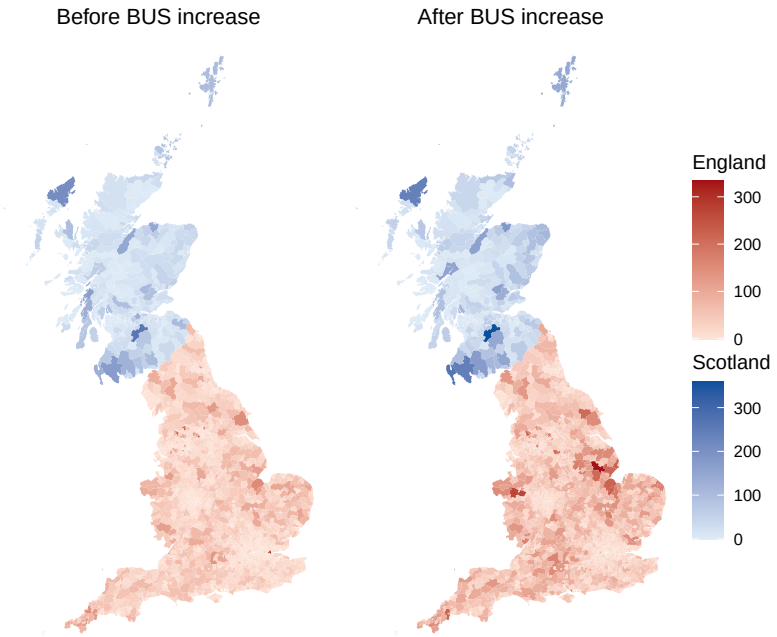
To study price incidence, we use the installation-level reported gross cost P_i, expressed in constant 2023 pounds using the ONS Consumer Price Index and cleaned of zero entries and extreme outliers above the 95th percentile (approximately £16,800) or outside the 1st–99th percentiles of capacity, as detailed in Appendix A.1. In Appendix A.1, we verify that this field records the gross contract invoice before deducting the BUS voucher: the May 2022 introduction of the £5,000 BUS

[3] In the current data pipeline, the monthly ASHP installation counts are constructed from records with non-missing cleaned capacity between 3 and 16 kW. In contrast, the installation-level cost regressions retain all heat pump technologies passing the cost and capacity cleaning rules in Appendix A.1, though ASHPs represent 93% of observations.

voucher in England and Wales produced no corresponding step drop in reported MCS costs (a difference-in-differences estimate at scheme launch yields $-£326$, s.e. $= £119$), and the average reported cost of £1,675 per kW aligns with industry benchmarks for gross domestic installations.

Our main causal estimation sample is a balanced monthly panel of LSOAs covering Northern England and Scotland over the 57-month window from October 2020 ($\text{rel}_\tau = -36$) through June 2025 ($\text{rel}_\tau = +20$). We form the Cartesian product of all LSOAs in the retained geography and all 57 calendar months, setting $Y_{i\tau}^{AHP} = 0$ in cells without recorded commissionings. Retaining zero-count cells ensures that the panel captures changes in installation frequency across both the intensive and extensive margins. Fixed-effects Poisson estimation drops LSOAs with zero installations across all 57 months, yielding an estimation panel of 12,992 LSOAs (740,544 LSOA-month observations). Figure 1 maps the geographic distribution of ASHP installations across Great Britain before and after October 2023 and highlights the Northern England treatment region and the Scottish comparison group. Appendix Figure G.2 confirms that monthly MCS air-source commissionings track official BUS voucher redemptions closely around the October 2023 reform.

Figure 1: Geographic distribution of ASHP installations before and after the October 2023 BUS grant increase



Notes: The figure maps the density of air-source heat pump installations recorded in MCS commissioning data across Great Britain, comparing the period before the BUS grant increase (left panel) to the period after (right panel), where before and after are defined relative to October 2023. Shading reflects installation counts per LSOA over the relevant period. The highlighted regions in red indicate the treatment group with the Scotland comparison group appearing in blue.

3.3 Pre-policy installer competition and supply-side measures

We measure pre-existing local installer competition at the TTWA level using installation shares accumulated prior to the BUS programme. For each TTWA m, let N_{jm} denote the number of heat pump installations completed in TTWA m by installer j between 2015 and 2021 (irrespective of where installer j is headquartered). We compute installer market shares $\omega_{jm} = N_{jm} / \sum_k N_{km}$, form the inverse Herfindahl–Hirschman index HHI_m^{-1} as in equation (4), and standardise it across TTWAs:

$$A_m \equiv \frac{\mathrm{HHI}_m^{-1} - \overline{\mathrm{HHI}^{-1}}}{\mathrm{sd}(\mathrm{HHI}^{-1})}. \tag{6}$$

Higher values of A_m correspond to less concentrated, more competitive local installer markets. Using the 2015–2021 window ensures that A_m is predetermined with respect to both the May 2022 BUS launch and the October 2023 grant increase. Appendix C.1 shows robustness to earlier pre-policy windows (including 2015–2019) and alternative market-thickness proxies such as active installer density, Shannon entropy, the four-firm concentration ratio, and certified installer headquarters density.

To examine how local supply adjusts after the October 2023 reform, we construct four LSOA-month mechanism outcomes from the installation records and installer registry: (i) the number of distinct active installers completing at least one ASHP installation in the LSOA-month, (ii) the number of active installers in the LSOA-month whose registered headquarters lies outside the LSOA's TTWA, (iii) the share of installations in the LSOA-month performed by such outside-TTWA installers ("off-site" installations), and (iv) the log of the mean great-circle (haversine) distance in kilometres between the installation postcode centroid and the installer's registered headquarters.

4 Empirical strategy

4.1 Difference-in-differences design

We estimate the effect of the October 2023 BUS grant increase on monthly LSOA air-source heat pump installations $Y_{i,\tau}$ by comparing Northern England ($E_i = 1$) with Scotland ($E_i = 0$) before and after October 2023 ($\mathrm{Post}_\tau = \mathbb{1}\{\mathrm{rel}_\tau \geq 0\}$). Because LSOA monthly counts are non-negative integers with many zeros, we estimate the conditional mean via Poisson pseudo-maximum likelihood (PPML) (Santos Silva & Tenreyro, 2006):

$$\mathbb{E}\left[Y_{i,\tau} \mid \alpha_i, \delta_\tau, \delta_\tau^R\right] = \exp\Big(\alpha_i + \delta_\tau + \delta_\tau^R \,\mathrm{Rural}_i + \beta\, E_i \times \mathrm{Post}_\tau\Big). \tag{7}$$

Here α_i are LSOA fixed effects, which absorb time-invariant cross-sectional differences in housing stock, off-gas-grid status, baseline market structure, and the different population sizes of English LSOAs and Scottish Data Zones. The calendar year-month fixed effects δ_τ absorb seasonal fluctua-

tions and UK-wide macroeconomic or energy-price shocks common to England and Scotland, while rural-LSOA-by-month fixed effects $\delta_\tau^R \,\mathrm{Rural}_i$ allow rural and urban areas to follow distinct monthly trajectories. Standard errors are clustered at the LSOA level throughout (Cameron et al., 2011).

The coefficient β measures the log incidence-rate ratio of the BUS grant increase on commissioned installations in Northern England relative to Scotland, with $\exp(\beta) - 1$ giving the proportional change. Identification rests on the conditional parallel-trends assumption that, absent the October 2023 BUS increase, expected installations in Northern England and Scotland would have followed parallel paths conditional on LSOA, month, and rural-by-month fixed effects, and that no contemporaneous policy or reporting shock differentially affected Scotland in late 2023.

To inspect pre-reform trends and trace the time path of the response, we estimate the event-study specification

$$\mathbb{E}\left[Y_{i,\tau} \mid \alpha_i, \delta_\tau, \delta_\tau^R\right] = \exp\left(\alpha_i + \delta_\tau + \delta_\tau^R \,\mathrm{Rural}_i + \sum_{k \in \mathcal{K} \setminus \{-1\}} \beta_k \, E_i \times \mathbb{1}_{\mathrm{rel}_\tau = k}\right), \tag{8}$$

over event months $\mathcal{K} = \{-20, \ldots, 20\}$, normalising on the pre-reform month $\mathrm{rel}_\tau = -1$ (September 2023) while estimating the fixed effects on the full -36 to $+20$ window. We test the joint nullity of the pre-implementation coefficients $\{\beta_k : k \leq -2\}$ via a Wald test.

4.2 Heterogeneity by pre-policy installer competition

To test whether the same demand subsidy produces a larger quantity response in less concentrated local installer markets, we interact the difference-in-differences terms with the predetermined TTWA competition index A_m defined in equation (6):

$$\mathbb{E}\left[Y_{i,\tau} \mid \alpha_i, \delta_\tau, \delta_\tau^R\right] = \exp\left(\alpha_i + \delta_\tau + \delta_\tau^R \,\mathrm{Rural}_i + \lambda_1 \,\mathrm{Post}_\tau \times A_m + \beta \, E_i \times \mathrm{Post}_\tau + \eta \, E_i \times \mathrm{Post}_\tau \times A_m\right). \tag{9}$$

The time-invariant main effect of A_m and its country interaction $E_i \times A_m$ are absorbed by the LSOA fixed effects α_i, while $\mathrm{Post}_\tau \times A_m$ absorbs any post-October 2023 shift associated with market thickness that is common to England and Scotland. To ensure that A_m does not merely proxy for differential trends in areas with higher initial heat pump familiarity, all interacted specifications additionally control for $\mathrm{Post}_\tau \times N_i^{HP}$ and $E_i \times \mathrm{Post}_\tau \times N_i^{HP}$, where N_i^{HP} is the pre-treatment count of heat pump installations in LSOA i. We also estimate a non-parametric variant that replaces A_m with an indicator for TTWAs in the top quartile of HHI_m^{-1} (relative to the lower three quartiles).

In equation (9), β gives the log treatment effect at the reference values ($A_m = 0$ and $N_i^{HP} = 0$), and η captures how the England–Scotland treatment effect varies with a one-standard-deviation increase in pre-policy installer competition. Interpreting η as heterogeneity in the policy response requires that, absent the October 2023 BUS reform, changes in the England–Scotland installation gap would not have varied systematically with A_m conditional on the fixed effects, lower-order competition interactions, and baseline-adoption controls.

4.3 Price and mechanism specifications and identification threats

We apply the same empirical design to installation costs and supply-side adjustment outcomes. For the price analysis, we estimate ordinary least squares (OLS) regressions at the individual installation level on the 68,560 observations with cleaned reported costs P_i, retaining the LSOA, year-month, and rural-by-month fixed effects as well as the pre-treatment LSOA installation interactions. Because the composition of installed heat pumps can shift in response to the grant, we estimate a sequence of nested specifications that first omit system controls, then control for installed thermal capacity K_i (kW), and finally include installer-by-heat pump-model pair fixed effects so that price changes are identified within an exact firm–product match.

For the LSOA-month mechanism outcomes in Section 5.2, we estimate counts of active installers and outside-TTWA active installers by PPML on the balanced panel, and estimate the off-site installation share and log mean headquarters distance by OLS on the subset of LSOA-months containing at least one geocoded installation. Installation-level technical characteristics (capacity, rated SCOP, design flow temperature, and annual heat demand) are estimated by OLS with installer fixed effects on the cost sample.

Two potential threats to identification merit discussion. First, because commissioning dates mark project completion, anticipation of the October 2023 increase could lead installers or households to delay September completions into October. Such intertemporal shifting would show up as a dip immediately prior to implementation followed by a short-lived spike. The event-study path in equation (8) allows us to evaluate whether the response is a transitory bunching artifact or a persistent shift in installation rates. Second, installers near the Anglo-Scottish border could reallocate capacity from Scotland to Northern England after the English grant rises, which would depress Scottish installations and overstate the net national expansion. Our spatial mechanism regressions directly examine whether cross-TTWA installer travel and outside-market entry account for the observed quantity response, and Appendix J checks sensitivity to excluding border-straddling TTWAs.

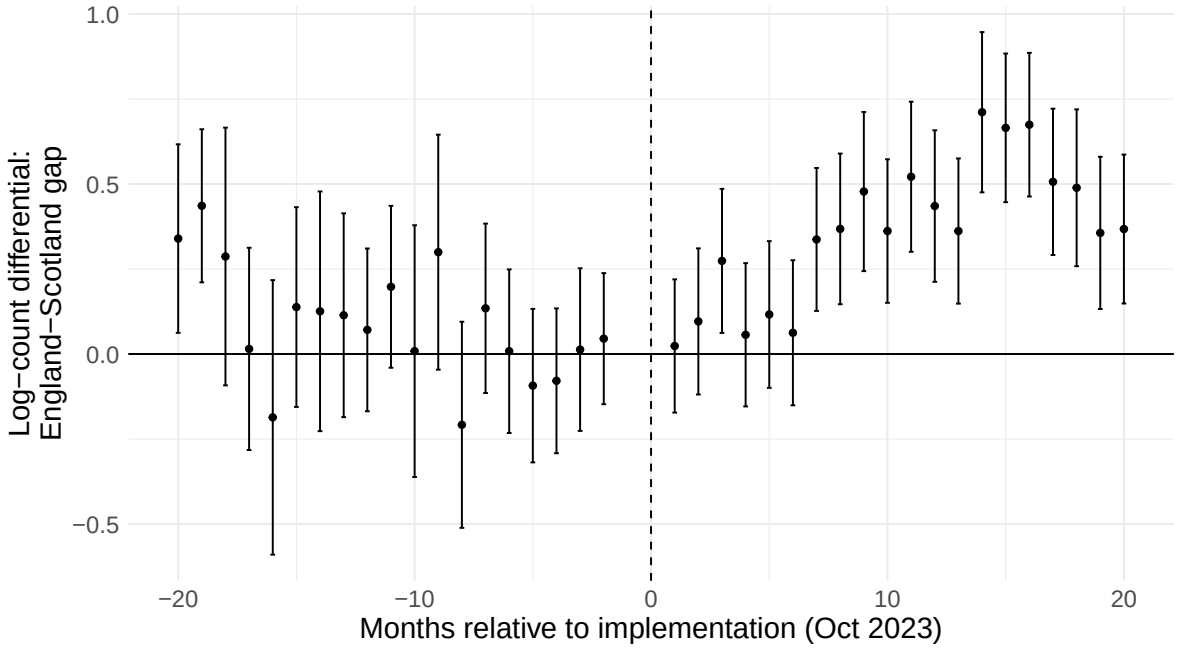
5 Results

5.1 Quantity and price responses

Figure 2 plots the monthly event-study coefficients β_k from equation (8). Prior to the October 2023 grant increase, the England–Scotland differential fluctuates around zero with no discernible trend, and a joint Wald test of the pre-implementation coefficients yields $p = 0.35$. Following implementation, installations in Northern England rise relative to Scotland and remain elevated throughout the 20 post-reform months.

Table 1 presents the corresponding PPML difference-in-differences estimates for monthly LSOA installation counts (full coefficient sets including lower-order interactions appear in Appendix Ta-

Figure 2: England–Scotland event study for ASHP installations



Notes: The figure reports event-study coefficients from a Poisson fixed-effects regression of monthly ASHP installation counts at the LSOA level for Northern England and Scotland. The plotted points correspond to the interaction between an England indicator and event-time indicators for months relative to October 2023 (the BUS implementation month). The omitted reference month is event time −1. Error bars are 95 percent confidence intervals based on standard errors clustered by LSOA. The specification includes LSOA fixed effects, calendar year-month fixed effects, and rural-LSOA-by-month fixed effects. The model uses months −36 to +20 relative to October 2023; the figure displays months −20 to +20. Coefficients are in log-count units (log incidence-rate ratios) and can be exponentiated to obtain multiplicative effects on the conditional mean.

ble C.1). In the baseline specification in column (1), the BUS grant increase raises monthly ASHP installations in Northern England by 0.212 log points (s.e. = 0.045), or 23.6% (exp(0.212) − 1). Controlling for interactions with pre-treatment LSOA heat pump installations in column (2) yields a similar coefficient of 0.168 (s.e. = 0.045).

Columns (3) and (4) show that the quantity expansion is substantially stronger in less concentrated installer markets. In column (3), the triple-interaction coefficient on BUS increase × Competition is 0.125 (s.e. = 0.049), on top of a main effect of 0.171 at the reference point. Evaluated at mean competition ($A_m = 0$), the grant increase raises installations by 18.6%. One standard deviation above the mean ($A_m = 1$), the proportional response rises to 34.3%. Replacing the continuous index in column (4) with an indicator for TTWAs in the top quartile of pre-policy inverse HHI yields a differential response of 0.289 log points (s.e. = 0.081) above a base effect of 0.105 in the lower three quartiles.[4]

Table 2 turns to the installation-level OLS regressions for reported pre-grant installation cost

[4]Appendix Table C.2 shows that interacting the treatment with the pre-policy number of active installers per 1,000 residents yields a positive interaction of 0.161 (s.e. = 0.058) when entered alone and 0.151 (s.e. = 0.059) alongside A_m, whose own coefficient remains 0.128 (s.e. = 0.049).

Table 1: England–Scotland DiD estimates of the BUS effect on ASHP installations

	Count of ASHP installations (PPML)			
	(1)	(2)	(3)	(4)
BUS increase	0.212***	0.168***	0.171***	0.105**
	(0.045)	(0.045)	(0.044)	(0.052)
BUS increase × Competition			0.125**	
			(0.049)	
BUS increase × Top-quartile competition				0.289***
				(0.081)
Time FE (monthly)	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes
Pre-treatment HP installs		Yes	Yes	Yes
Observations	740,544	740,544	740,544	740,544
AIC	422,051	420,691	420,629	420,646

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Coefficients from a Poisson fixed-effects regression of monthly ASHP installation counts at the LSOA-month level, estimated by PPML, equations (7) and (9). "BUS increase" is the England-by-post coefficient β. Column (1) is the baseline specification; column (2) adds the pre-treatment HP installs control; columns (3) and (4) add, respectively, the continuous competition interaction and the top-quartile inverse-HHI interaction. All specifications include LSOA fixed effects, calendar year-month fixed effects, and rural-LSOA-by-month fixed effects. The sample is the balanced panel of the 12,992 LSOAs with at least one ASHP installation in the window, over months −36 to +20 around implementation. Standard errors (in parentheses) are clustered by LSOA.

(Appendix Table C.3 reports all lower-order interactions). Without controlling for system characteristics, reported gross cost falls by £758 (s.e. = £121) after the BUS increase in column (1), and by £827 (s.e. = £122) at the reference competition level in column (4), with an additional decline of £333 (s.e. = £111) per standard deviation of pre-policy competition. Because this cost variable is recorded before deducting the £2,500 BUS grant increase, a negative coefficient indicates that household out-of-pocket costs fell by more than the subsidy increment.

A decline in average invoice cost can reflect two distinct forces: a competitive reduction in installer prices for a given system, or a compositional shift toward smaller and cheaper heat pump installations induced by the higher grant. Columns (2)–(3) and (5)–(7) separate these margins by progressively adding controls for installed thermal capacity (kW) and installer-by-heat-pump-model pair fixed effects. Controlling for capacity reduces the estimated cost drop from £758 to £448 in column (2) and from £827 to £528 in column (5), while the continuous competition interaction moves from −£333 to −£251 (s.e. = £101). Adding fixed effects for every installer × MCS-product-number pair in columns (3) and (6) absorbs all variation across firms and heat pump models. Within an installer–model pair at fixed capacity, the average post-reform price change

Table 2: England–Scotland DiD estimates of the BUS effect on installation cost

	ASHP installation cost						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BUS increase	-757.824***	-448.144***	-152.184*	-826.665***	-527.953***	-206.463**	-121.347
	(120.539)	(108.934)	(88.117)	(122.227)	(110.576)	(90.614)	(94.761)
HP capacity		364.507***	323.732***		364.495***	323.880***	323.766***
		(5.202)	(14.689)		(5.200)	(14.685)	(14.689)
BUS increase × Competition				-333.072***	-251.132**	-168.577**	
				(111.225)	(100.610)	(75.111)	
BUS increase × Top-quartile competition							-191.346
							(141.342)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Installer × HP model FE			Yes			Yes	Yes
Observations	68,560	68,560	68,560	68,560	68,560	68,560	68,560
AIC	1,294,250	1,284,064	1,232,029	1,294,233	1,284,050	1,232,017	1,232,029

* p < 0.1, ** p < 0.05, *** p < 0.01

Notes: OLS estimates for reported installation cost in pounds at the installation level (cleaned as described in Appendix A.1). "BUS increase" is the England-by-post coefficient β. Column (1) is the baseline specification; column (2) adds installed capacity (kW) as a control; column (3) adds a fixed effect for each installer × heat pump-model pair, so that the effect is identified from the same installer selling the same model (singleton pairs are kept); column (4) adds the continuous competition interaction without the capacity control; column (5) adds the capacity control to it; column (6) adds the installer × heat-pump-model fixed effect to column (5); column (7) replaces the continuous competition index in column (6) with the top-quartile inverse-HHI indicator, keeping the capacity control and the installer × heat-pump-model fixed effect. All columns include the pre-treatment HP installs control and LSOA, calendar year-month, and rural-LSOA-by-month fixed effects. The sample is the 68,560 installations with a usable reported cost in months −36 to +20 around implementation. Standard errors (in parentheses) are clustered by LSOA.

is $-£152$ (s.e. $= £88$, $p < 0.10$) in column (3), and $-£206$ (s.e. $= £91$, $p < 0.05$) at reference competition in column (6) with a statistically significant competition gradient of $-£169$ (s.e. $= £75$) per standard deviation. Replacing the continuous competition index in column (6) with the top-quartile indicator in column (7) yields a point estimate of $-£191$ (s.e. $= £141$), which is similar in magnitude but not statistically significant under the demanding within-pair restriction.

Overall, Table 2 shows that while compositional shifts toward smaller and lower-cost systems explain a substantial fraction of the £827 unconditional invoice decline, pre-grant prices also fall within exact installer–model pairs, particularly in more competitive local markets. We retain the unconditional column (4) estimate of $-£827$ as our headline invoice response, since endogenous adjustments in system choice are themselves part of the policy response, and formally decompose it into capacity, composition, and within-pair components in Section 5.3.

5.2 Installer entry, spatial reach, and system characteristics

Table 3 examines how local supply and system specifications adjust following the October 2023 reform (full interaction coefficients are reported in Appendix Table C.4). Panel A focuses on LSOA-month measures of installer participation and geographic reach.

Table 3: Mechanisms: installer activity, spatial allocation, and the characteristics of installed systems

Panel A: Installer activity and spatial allocation								
	Active installers		Installers based outside the TTWA		Share of off-site installations		Distance to installer	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BUS increase	0.172***	0.177***	0.373***	0.392***	0.022*	0.037***	0.263***	0.288***
	(0.031)	(0.031)	(0.037)	(0.038)	(0.013)	(0.013)	(0.042)	(0.042)
BUS increase × Competition		0.105***		0.274***		0.025*		0.027
		(0.030)		(0.038)		(0.013)		(0.041)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	738,777	738,777	618,450	618,450	44,491	44,491	44,491	44,491
AIC	384,272	384,245	276,971	276,881	37,903	37,875	142,292	142,286
Panel B: Characteristics of installed systems								
	HP capacity (kW)		SCOP		Flow temperature (°C)		Annual heating demand (kWh)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BUS increase	-0.570***	-0.595***	0.052***	0.046***	-0.540***	-0.444***	-549.448	-710.427
	(0.096)	(0.100)	(0.011)	(0.011)	(0.119)	(0.123)	(583.161)	(574.547)
BUS increase × Competition		-0.029		-0.010		0.063		-236.690
		(0.091)		(0.010)		(0.113)		(369.426)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Installer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	68,560	68,560	68,029	68,029	68,029	68,029	68,560	68,560
AIC	333,844	333,846	13,109	13,103	344,991	344,967	1,604,518	1,604,522

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: In Panel A the dependent variables are defined at the LSOA-month on the same panel as Table 1 (the 12,992 LSOAs with at least one ASHP installation in the window): the number of distinct installers with at least one ASHP installation in the LSOA in the month (columns 1–2); the number of those whose registered headquarters lies outside the LSOA's TTWA (columns 3–4); the share of the LSOA-month's installations carried out by installers based outside the TTWA ("off-site", columns 5–6); and the log of the mean straight-line distance between the installation postcode centroids and the installer headquarters (columns 7–8). Columns 1–4 are estimated by PPML, which drops LSOAs whose count is zero in every month; columns 5–8 by OLS on LSOA-months with at least one installation whose installer has a geocoded registered headquarters. In Panel B the dependent variables are characteristics of the installed system, measured at the installation level: installed capacity in kW, rated SCOP, design flow temperature, and annual heating demand in kWh; these specifications include installer fixed effects, so the coefficients identify changes within installers rather than reallocation across them. In both panels, odd-numbered columns report the England–Scotland specification, equation (7), with the pre-treatment HP installs control; even-numbered columns add the competition interaction from equation (9). All specifications include LSOA, calendar year-month and rural-LSOA-by-month fixed effects. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to +20 around implementation. Panel B is estimated at the installation level on the cleaned cost sample.

In column (1) of Panel A, the number of distinct active installers completing an installation in an English LSOA-month increases by 0.172 log points (18.8%) relative to Scotland after the grant increase, and column (2) shows that this increase is larger in more competitive TTWAs (0.105

log points, or roughly 11%, per standard deviation of A_m). Columns (3) and (4) isolate active installers whose registered headquarters lies outside the LSOA's TTWA: their count increases by 0.373 log points (45.2%) on average, with a competition interaction of 0.274 log points (31.5%). Because local incumbents also expand output, the share of installations performed by outside-TTWA firms rises more modestly, by 2.2 percentage points (s.e. = 1.3, $p < 0.10$) in column (5), and by 3.7 percentage points (s.e. = 1.3) at reference competition in column (6) with an interaction of 2.5 percentage points (s.e. = 1.3, $p < 0.10$) per standard deviation. Consistent with established installers extending their service radius into neighbouring markets, column (7) shows that the mean straight-line distance between an installation and its installer's headquarters increases by 0.263 log points (about 30%, or 18 km on a pre-policy geometric mean of 60 km). The competition interaction in column (8) is small and statistically indistinguishable from zero (0.027, s.e. = 0.041). Estimating the distance and off-site specifications at the individual installation level in Appendix Table G.1 yields virtually identical results (31% longer distance and a 2.6 percentage-point higher off-site share, with insignificant competition interactions).

Panel B of Table 3 examines changes in the technical specifications of installed systems at the installation level, conditioning on installer fixed effects so that estimates reflect within-installer shifts in equipment and project characteristics. Following the grant increase, average installed thermal capacity falls by 0.570 kW (s.e. = 0.096, column 1), design flow temperature falls by 0.540°C (s.e. = 0.119, column 5), and rated SCOP increases by 0.052 (s.e. = 0.011, column 3), while estimated annual heating demand shows no statistically significant change (−549 kWh, s.e. = 583, column 7). None of the competition interactions in even-numbered columns of Panel B is statistically significant. Thus, the shift toward smaller, lower-flow-temperature, higher-efficiency heat pumps occurs within continuing installers across the market as a whole, rather than concentrating in highly competitive TTWAs (see also Appendix Figure H.1 and Appendix Table H.1).

5.3 Decomposing the price response

To quantify how much of the headline cost reduction reflects smaller system sizes, shifts across heat pump models and installers, or lower prices charged by a given installer for a given model, we decompose the coefficients of column (4) in Table 2 using the nested specifications in columns (4), (5), and (6).[5] All three regressions are estimated by OLS on the same 68,560 installations with the same policy interactions ($E_i \, \text{Post}_\tau$, $E_i \, \text{Post}_\tau \, A_m$, and the pre-treatment adoption terms) and the same LSOA, year-month, and rural-by-month fixed effects:

(i) reported gross cost without capacity or pair controls (Table 2, column 4),

[5]While within-pair price reductions directly reflect lower prices charged for an identical model at fixed capacity, changes in the heat pump model or capacity fitted can also partly reflect competitive pressure if installers compete by offering units more closely tailored to smaller dwellings. The within-pair component can therefore be viewed as a conservative measure of price-conduct adjustments, subject to the caveat that we do not observe installer marginal costs or unmeasured dwelling installation complexity.

(ii) adding installed capacity K_i as a control (Table 2, column 5), and

(iii) adding both installed capacity K_i and installer-by-heat-pump-model pair fixed effects a_{jh} (Table 2, column 6).

Letting $\theta^{(i)}, \theta^{(ii)}, \theta^{(iii)}$ denote either the main BUS-increase coefficient β or the competition interaction η across the three models, we have the exact identity

$$\theta^{(i)} = \underbrace{\left[\theta^{(i)} - \theta^{(ii)}\right]}_{\text{capacity}} + \underbrace{\left[\theta^{(ii)} - \theta^{(iii)}\right]}_{\text{installer and model composition}} + \underbrace{\theta^{(iii)}}_{\text{within pair}}. \tag{10}$$

By the Frisch–Waugh–Lovell theorem, the first bracket equals the capacity slope from regression (ii), $\hat{\gamma} = £364.5$ per kW, multiplied by the effect of the policy term on installed capacity K_i estimated with the right-hand side of regression (i). The third term $\theta^{(iii)}$ is the within-installer-and-model price change at fixed capacity. The middle bracket $\theta^{(ii)} - \theta^{(iii)}$ captures the cost change due to compositional shifts across installers and heat pump models.

To separate this middle bracket into product-mix and installer-reallocation subcomponents, we recover the estimated pair fixed effects $\hat{a}_{jh}$ from regression (iii), where j indexes installers and h indexes the 1,008 distinct MCS product numbers in the sample.[6] We decompose each pair effect into an installation-weighted product mean $\hat{\mu}_h$ and a residual installer premium $\hat{\pi}_{jh}$:

$$\hat{a}_{jh} = \hat{\mu}_h + \hat{\pi}_{jh}, \qquad \hat{\mu}_h \equiv \frac{\sum_j n_{jh}\,\hat{a}_{jh}}{\sum_j n_{jh}},$$

where n_{jh} is the sample count of installations of model h by installer j, so $\sum_j n_{jh}\,\hat{\pi}_{jh} = 0$ for every model h.[7] Using all MCS installation records in the estimation window, we then classify each installer j's activity in TTWA m into one of three mutually exclusive categories: *local entry* ($D_i^E = 1$) if installer j had zero installations in TTWA m before October 2023 and at least one after, *local exit* ($D_i^X = 1$) if installer j was active in TTWA m before October 2023 but not after, and *continuing* ($D_i^C = 1$) if active in both periods. Notice that entry and exit are defined at the local TTWA level: an established firm expanding into a new TTWA is coded as a local entrant there, with its premium $\hat{\pi}_{jh}$ estimated from all of its installations nationwide.

For each installation i, we form four variables that sum identically to $\hat{a}_{j(i)h(i)}$:

$$\begin{aligned} Y_i^{\text{model}} &= \hat{\mu}_{h(i)}, & Y_i^{\text{entry}} &= \hat{\pi}_{j(i)h(i)}\,D_i^E, \\ Y_i^{\text{exit}} &= \hat{\pi}_{j(i)h(i)}\,D_i^X, & Y_i^{\text{cont}} &= \hat{\pi}_{j(i)h(i)}\,D_i^C, \end{aligned} \tag{11}$$

[6] Singleton installer–model pairs (5,225 installations across 10,293 pairs) are retained so that all three regressions share the exact 68,560-observation sample. Because the multi-way fixed-effect design matrix is rank-deficient, we take the minimum-norm solution to fix the overall level of $\hat{a}_{jh}$.

[7] Alternative decompositions of $\hat{a}_{jh}$, such as unweighted model means or jointly estimated additive installer and model effects, leave the total composition term $\theta^{(ii)} - \theta^{(iii)}$ unchanged while reallocating weight between the model and installer rows.

and estimate regression (ii) on the full 68,560-installation sample using each component $k \in \{\text{model}, \text{entry}, \text{exit}, \text{cont}\}$ as the dependent variable:

$$Y_i^k = \beta^k E_i \,\text{Post}_{\tau(i)} + \eta^k E_i \,\text{Post}_{\tau(i)} A_{m(i)} + \gamma^k K_i + (\text{remaining terms of (ii)}) + \alpha_{\ell(i)} + \delta_{\tau(i)} + \delta^R_{\tau(i)} \,\text{Rural}_i + u_i^k. \tag{12}$$

Because OLS is linear in the dependent variable and $\sum_k Y_i^k = \hat{a}_{j(i)h(i)}$, the estimated coefficients satisfy $\sum_k \hat{\beta}^k = \beta^{(ii)} - \beta^{(iii)}$ and $\sum_k \hat{\eta}^k = \eta^{(ii)} - \eta^{(iii)}$ exactly.[8]

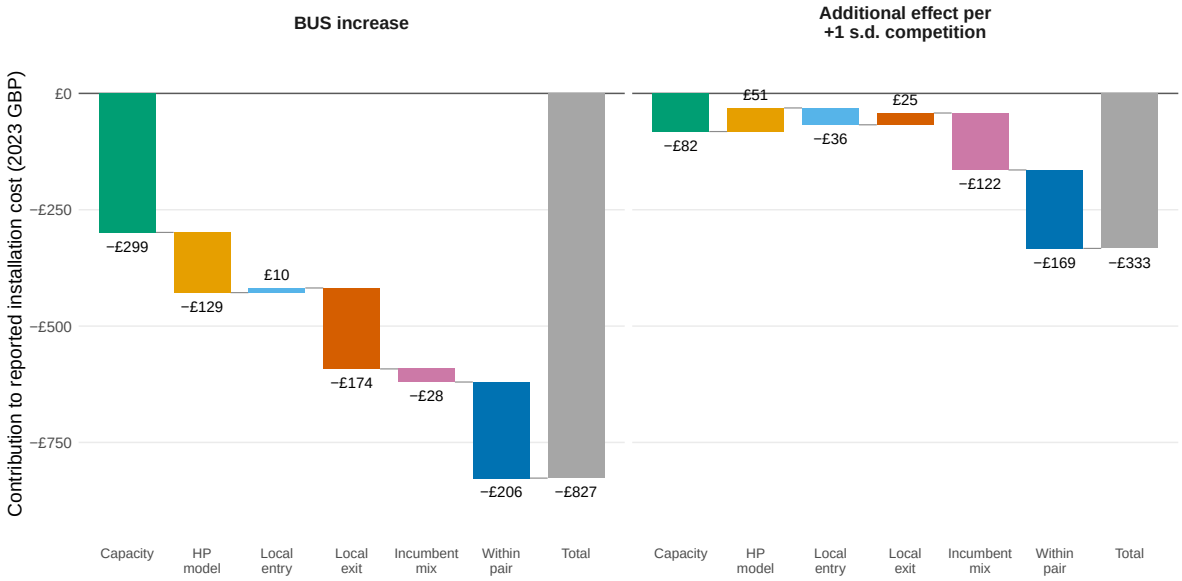
Table 4: Decomposition of the cost response (£per installation)

	Component	BUS increase (β)	per s.d. competition (η)
$\theta^{(i)} - \theta^{(ii)}$	Installed capacity	−298.7	−81.9
$\theta^{(ii)} - \theta^{(iii)}$	HP-model mix	−129.4	+50.7
	Local installer entry	+10.0	−36.2
	Local installer exit	−173.9	+25.3
	Continuing-installer reallocation	−28.2	−122.4
	Composition, total	−321.5	−82.6
$\theta^{(iii)}$	Within installer × model	−206.5	−168.6
$\theta^{(i)}$	Total	−826.7	−333.1

Notes. Rows sum exactly to the total within each column. Capacity = 364.5× the policy effect on installed capacity (−0.82 kW; −0.22 kW per s.d. of competition), estimated with the right-hand side of regression (ii). The four composition rows are the coefficients $\hat{\beta}^k$ and $\hat{\eta}^k$ of equation (12), with the outcomes defined in equation (11). Within = the coefficients of regression (iii).

[8] While the four-way composition sum $\theta^{(ii)} - \theta^{(iii)}$ and the split between $\hat{\mu}_h$ and $\sum_{k \neq \text{model}} Y_i^k$ are invariant to adding a constant to all $\hat{\pi}_{jh}$, the allocation across the three installer sub-rows (entry, exit, continuing) depends on the minimum-norm and within-model centring normalisation because the shares of D_i^E, D_i^X, D_i^C shift with the policy.

Figure 3: Decomposition of the BUS effect on installation cost



Notes. Left: components of the BUS-increase coefficient; right: components of its interaction with the competition index (per standard deviation). Totals are the coefficients of regression (i), column (4) of Table 2: no capacity control, evaluated at a competition index of zero and zero pre-treatment adoption. Numbers as in Table 4.

Table 4 and Figure 3 report the decomposition for both the main BUS-increase coefficient ($\beta^{(i)} = -£826.7$) and the competition interaction ($\eta^{(i)} = -£333.1$ per standard deviation). For the main effect at the reference point, reductions in installed system capacity (−0.82 kW multiplied by £364.5/kW) account for $-£298.7$, and shifts in model and installer composition account for $-£321.5$ (comprising $-£129.4$ from a shift toward lower-cost heat pump models, $+£10.0$ from local installer entry, $-£173.9$ from the local exit of high-cost installers, and $-£28.2$ from market-share reallocation among continuing local installers). The remaining $-£206.5$, or one quarter of the total invoice decline, occurs within an identical installer–model pair at fixed capacity.

For the competition gradient, within-pair price reductions play the dominant role. Of the additional $-£333.1$ cost reduction per standard deviation of pre-policy competition, fully half ($-£168.6$) occurs within installer–model pairs. Composition accounts for $-£82.6$, driven primarily by reallocation toward lower-priced continuing installers ($-£122.4$) and lower-priced local entrants ($-£36.2$), partially offset by a shift toward more expensive heat pump models ($+£50.7$) and local exit ($+£25.3$). The remaining $-£81.9$ comes from a larger reduction in installed capacity in more competitive markets (−0.22 kW per standard deviation without installer fixed effects, compared with the near-zero −0.029 kW within-installer interaction in Table 3, Panel B), indicating that competitive markets also reallocate customers toward installers that fit smaller systems.[9]

[9]Because a heat pump model's product code largely pins down its thermal output, the individual capacity ($-£298.7$) and model-mix ($-£129.4$) components are less cleanly separated than their combined product-characteristics sum ($-£428.1$). Standard errors for the underlying regression coefficients $\theta^{(i)}, \theta^{(ii)}, \theta^{(iii)}$ are reported in Table 2, columns (4)–(6).

5.4 Correlates of local installer competition

Because both the quantity expansion and the price response to the BUS grant increase are substantially stronger in TTWAs with higher pre-policy installer competition, we next examine which local supply- and demand-side factors are associated with initial market structure. We estimate a cross-sectional regression across the $N = 31,441$ English LSOAs with complete covariate data (spanning 155 TTWAs):

$$A_{m(i)} = \alpha + \mathbf{x}_i'\boldsymbol{\beta} + \varepsilon_i, \tag{13}$$

where $A_{m(i)}$ is the standardised 2015–2021 inverse HHI of the TTWA $m(i)$ containing LSOA i, and $\mathbf{x}_i$ is a vector of 18 local covariates (6 supply-side and 12 demand-side proxies, curated from a broader set of 38 candidate variables, as detailed in Appendix Table J.3). All continuous covariates are standardised into z-scores on the estimation sample, while an indicator for whether a Green Party candidate stood in the 2019 general election enters in levels. Standard errors are clustered at the TTWA level (155 clusters).

To identify the most informative predictors among the 18 correlated covariates, we estimate a Lasso specification (Belloni & Chernozhukov, 2013):

$$\hat{\boldsymbol{\beta}}^{L}(\lambda) = \arg\min_{\alpha,\boldsymbol{\beta}} \frac{1}{2N}\sum_{i=1}^{N}\left(A_{m(i)} - \alpha - \mathbf{x}_i'\boldsymbol{\beta}\right)^2 + \lambda\sum_{k=1}^{18}|\beta_k|, \tag{14}$$

selecting the penalty parameter λ via ten-fold cross-validation in which entire TTWAs are assigned to folds (using the one-standard-error rule), and then re-estimating equation (13) by post-Lasso OLS on the selected variables.

Figure 4 plots the full 18-variable OLS estimates alongside the post-Lasso OLS estimates. The cluster-cross-validated Lasso selects five variables: three supply-side proxies (the synthetic local plumber wage index,[10] the construction self-employment share, and distance to the nearest approved heat pump training centre[11]) and two demand-side proxies (population density and long-term mean temperature). Together, these five variables yield an R^2 of 0.513, capturing 97% of the explanatory power of the full 18-variable OLS model ($R^2 = 0.530$).

[10] Constructed as the TTWA all-employee median gross hourly wage (2019 Annual Survey of Hours and Earnings, Table 11) multiplied by the population-weighted regional ratio of median pay for plumbers and heating/ventilating engineers (SOC 5314) to all occupations (ASHE 2019, Table 15).

[11] Great-circle distance from the LSOA centroid to the nearest provider listed under the Department for Energy Security and Net Zero's £500-per-trainee Heat Training Grant scheme as of 8 November 2023.

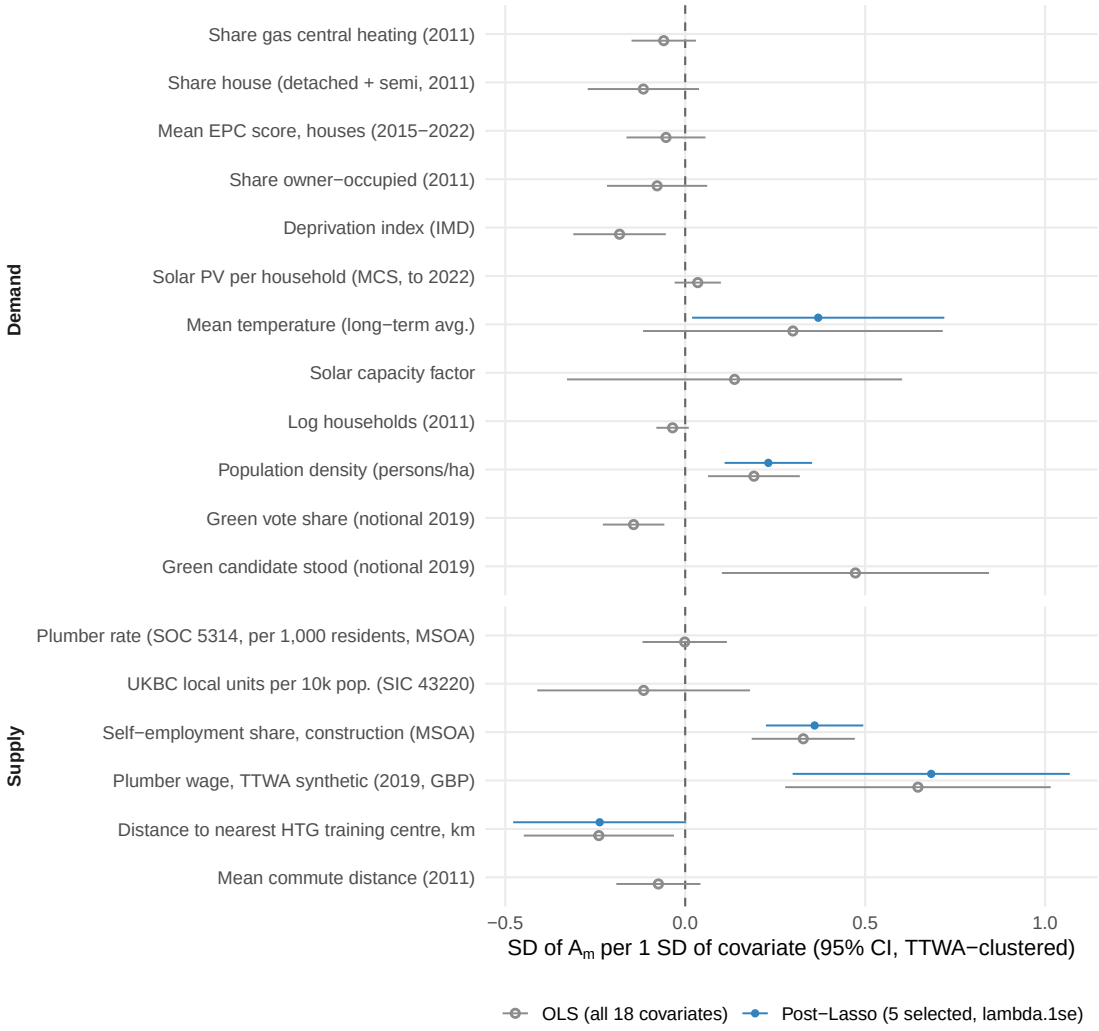


Figure 4: Correlates of local installer competition. Coefficients from equation (13) on 31,441 English LSOAs: OLS on all 18 covariates (hollow grey) and post-Lasso OLS on the five covariates selected by cluster-fold cross-validated Lasso (filled blue). Outcome: A_m, the standardised inverse HHI of 2015–2021 installer shares. Covariates standardised on the estimation sample; coefficients per standard deviation. Bars are 95 percent confidence intervals with standard errors clustered by TTWA (155 clusters).

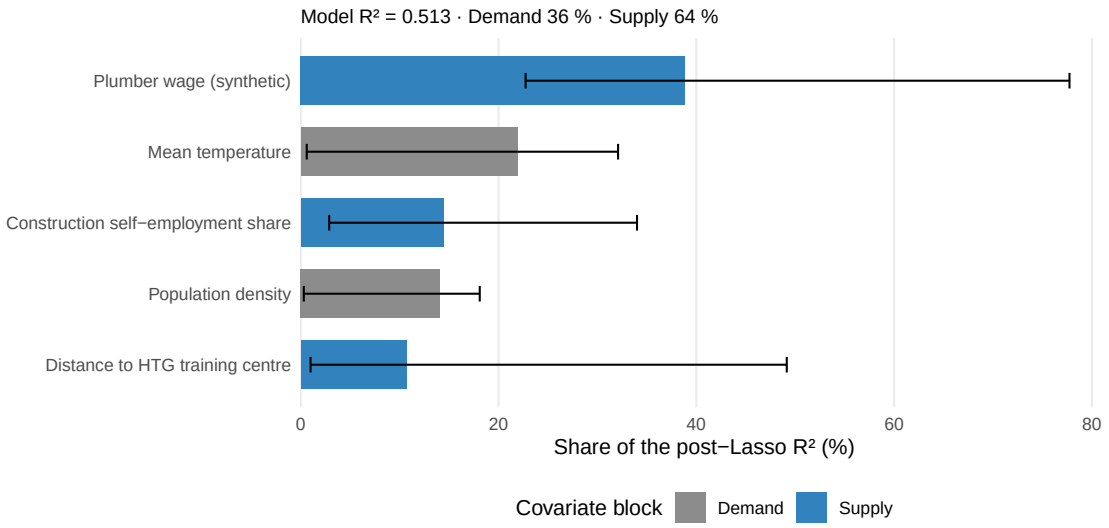


Figure 5: Shapley decomposition of the post-Lasso R^2. Bars show each Lasso-selected covariate's Shapley (LMG) share of the R^2 (0.513) of the post-Lasso OLS of A_m on the five selected covariates, with the selection held fixed; shares sum to 100 percent, and the subtitle gives the Demand and Supply subtotals. Whiskers are 2.5th to 97.5th percentiles of the share over 2,000 cluster-bootstrap draws of TTWAs. England estimation sample, 31,441 LSOAs in 155 TTWAs. The TTWA-level outcome is broadcast to LSOAs, so shares are LSOA-weighted; the decomposition is an in-sample, descriptive accounting of explained variation, not a causal attribution.

A Shapley (R^2) decomposition of the post-Lasso regression (Figure 5 and Appendix Table J.1) shows that the three supply-side variables account for 64% of the explained variance in local installer competition, whereas the two demand-side variables account for 36%. The plumber wage index alone accounts for 38.9% of explained variation: a one-standard-deviation higher plumber wage index is associated with a 0.68 s.d. increase in A_m in the post-Lasso specification (0.65 s.d. in the full OLS model). A one-standard-deviation higher construction self-employment share is associated with a 0.36 s.d. (0.33 s.d. full OLS) increase in competition, and a one-standard-deviation greater distance to a heat pump training centre is associated with a 0.24 s.d. (0.24 s.d. full OLS) reduction. Because one standard deviation of A_m corresponds to roughly 9 effective equal-sized installers (around a GB-wide TTWA mean of 15), these magnitudes correspond to roughly 6, 3, and 2 effective installers, respectively. On the demand side, a one-standard-deviation increase in population density is associated with a 0.23 s.d. increase in competition, consistent with standard market-size entry thresholds (Bresnahan & Reiss, 1991), while long-term mean temperature has a positive coefficient of 0.37 s.d.

Across 48 alternative specifications varied in Appendix J (Appendix Figure J.1), which change the unit of analysis to TTWA means, add region fixed effects, drop London or border TTWAs, swap variable proxies, and vary the concentration measure, the plumber wage index, construction self-employment share, training-centre distance, and population density retain their sign in almost every specification and have 95% confidence intervals excluding zero in 84% to 93% of specifications.

By contrast, mean temperature is sensitive to the inclusion of region fixed effects and alternative covariates, reaching statistical significance in only two of the 48 specifications. Although descriptive, the strong association between local installer competition and local trade wages, small-business prevalence in construction, and training-provider proximity suggests that local workforce capabilities and training access are important correlates of market thickness.

5.5 Placebo and robustness checks

We conduct a battery of robustness checks in Appendices C–E. First, Appendix Table C.5 re-estimates the baseline difference-in-differences model assigning placebo October reforms in 2018, 2019, 2021, and 2022: all four placebo coefficients are small and statistically insignificant (ranging from -0.092 to 0.097, compared with 0.203, $p < 0.01$, in the matched 2023 specification). Second, Appendix Tables C.6–C.9 confirm that the competition heterogeneity in quantities and prices holds across earlier HHI windows (2013–2015, 2013–2017, 2015–2017, and 2015–2019), alternative market-thickness measures (active-installer density, Shannon entropy, $1 - \text{CR}_4$, certified headquarters density, and historical 90th-percentile installer service reach), and when restricting the sample to the 83.8% of LSOAs lying within the common support of the English and Scottish competition distributions. Third, Appendix D tests for installer learning-by-doing and finds no evidence that cumulative installer experience with a specific heat pump model lowers reported installation costs ($\hat{\beta}_P \in [-0.003, 0.000]$, statistically insignificant), ruling out model-specific learning curves as an explanation for the post-reform price drop. Fourth, Appendix E shows that controlling for pre-policy peak throughput headroom at either the TTWA or installer level leaves the competition interaction on quantities unchanged at 0.133 (s.e. = 0.049).

6 Welfare and cost-effectiveness

We now combine our quantity and price estimates with engineering data from the MCS records to evaluate the marginal value of public funds (MVPF) and fiscal cost per tonne of carbon abated for the October 2023 BUS grant increase (Hahn et al., 2024; Hendren & Sprung-Keyser, 2020). Because our quasi-experimental design identifies behavioural responses to the £2,500 grant increment (from £5,000 to £7,500), our primary welfare evaluation is defined at that margin. We report calculations for the full £7,500 grant only as a sensitivity exercise under an assumed inframarginal share.

6.1 MVPF framework

Following Hendren and Sprung-Keyser (2020), the MVPF is the ratio of beneficiaries' aggregate willingness to pay for the policy change to its net fiscal cost to the government. Let $\Delta s = £2,500$ denote the October 2023 grant increase and let σ denote the fraction of post-implementation installations induced by the increase (so $1 - \sigma$ is the inframarginal share of adopters who would have

installed a heat pump at the £5,000 grant). Expressed per post-implementation installation,

$$\text{MVPF} \;=\; \frac{\Delta s\,[(1-\sigma)\lambda_I + \sigma\lambda_M] \;+\; \sigma\left(V^{\text{CO}_2} + V^{\text{AQ}}\right)}{G \;-\; \sigma F}. \tag{15}$$

In the numerator, inframarginal households value the additional grant pound for pound ($\lambda_I = 1$), while marginal adopters induced to switch by the grant increase value the transfer at $\lambda_M = 0.5$ under the standard Harberger triangle approximation. Each induced installation generates discounted lifetime carbon-abatement benefits V^{CO_2} and local air-quality benefits V^{AQ}, whereas inframarginal installations generate no additional environmental benefit. In the denominator, G is the gross public outlay per post-implementation adopter and F is the net fiscal externality per induced installation (comprising changes in value-added tax revenues from equipment and energy bills, emissions-trading receipts, and the UK's share of avoided global climate damages).

We report results under two accounting conventions for G. Our baseline convention follows Hendren and Sprung-Keyser (2020) and Hahn et al. (2024) by costing the policy strictly at the £2,500 increment being evaluated ($G = \Delta s = £2,500$). A broader fiscal-cost convention recognises that each marginal adopter induced by the reform also claims the pre-existing £5,000 base voucher (s^{old}), which the government would not otherwise have paid, raising the outlay per post-implementation adopter to $G = s^{\text{new}} - s^{\text{old}}(1-\sigma) = \Delta s + \sigma s^{\text{old}}$.

6.2 Abated emissions from MCS engineering records

Rather than relying on a single external archetype, we compute displaced energy use directly from the installation-specific engineering fields in the MCS database. For each installation i with annual design space- and water-heating demand Q_i (kWh) and rated seasonal performance SCOP_i, annual heat pump electricity consumption and counterfactual condensing gas boiler consumption (at seasonal efficiency $\eta = 0.85$) are

$$E_i \;=\; \frac{Q_i}{\text{SCOP}_i}, \qquad \text{Gas}_i \;=\; \frac{Q_i}{\eta}. \tag{16}$$

Summing over a 21-year appraisal horizon $\mathcal{T} = \{2023, \ldots, 2043\}$ yields lifetime abated emissions per installation:

$$T_i \;=\; \sum_{t \in \mathcal{T}} \left[\text{Gas}_i\,\phi_t^{\text{gas}} \;-\; E_i\,\phi_t^{\text{elec}}\right], \tag{17}$$

where ϕ_t^{gas} is the domestic natural-gas emission factor and ϕ_t^{elec} is the projected UK marginal grid electricity emission factor, which declines from 0.248 to 0.003 $\text{kgCO}_2\text{e/kWh}$ over 2023–2043 (Department for Energy Security and Net Zero, 2023). We value carbon savings using the UK government's central appraisal carbon price schedule (£265/tCO_2e in 2023, rising in real terms) discounted at the 3.5% Green Book social discount rate, discount air-quality health benefits at 1.5%, and discount private household energy expenditure at 5% (Department for Energy Security

and Net Zero, 2023; HM Treasury, 2022).

Averaging across the 24,170 post-reform English ASHP installations with complete technical fields (out of 88,606 usable records in the sample, reported in Appendix Table I.1, Panel A), the representative installation supplies 16,709 kWh of annual heat at a rated SCOP of 3.71, consuming 4,517 kWh of electricity and displacing 19,658 kWh of gas per year. Over the 2023–2043 horizon, this implies 68.4 tCO_2e of cumulative abatement, a discounted climate benefit of $V^{CO_2} = £14,849$, and an air-quality benefit of $V^{AQ} = £520$.

Because MCS heat demand is derived from standardised design heat-loss calculations and SCOP is a laboratory rating, both quantities exceed typical in-home metered performance. In a contemporaneous evaluation of the BUS using smart-meter data from a single energy supplier, Bernard et al. (2024) estimate an annual electricity increase of 3,080 kWh and a gas reduction of 9,351 kWh per heat pump, which implies 30.9 tCO_2e of lifetime abatement over the same horizon, less than half the MCS engineering figure. We therefore report all welfare metrics under both the MCS engineering basis and the metered-energy basis.

6.3 Behavioural parameters and elasticity

Panel B of Appendix Table I.1 summarises the behavioural inputs taken from Section 5. The baseline PPML coefficient $\hat{\beta} = 0.212$ (Table 1, column 1) implies a proportional quantity increase of $\widehat{\Delta Q}/Q = \exp(\hat{\beta}) - 1 = 0.236$, or 9.4% per £1,000 of grant (a grant elasticity of 0.47). The share of post-implementation installations induced by the grant increase is therefore $\sigma = 0.236/(1+0.236) = 0.191$. Applied to the cumulative event-study path in Appendix Figure G.4, the reform generated approximately 7,200 additional ASHP installations in the Northern England sample over the 20 post-reform months, corresponding to roughly 494,000 tCO_2e of lifetime engineering abatement.

Combining the £2,500 voucher increase with the headline gross invoice reduction of $\hat{\beta}^{\text{Cost}} = -£827$ (Table 2, column 4) yields an invoice-based household pass-through rate of

$$\hat{\rho} = \frac{\Delta s - \hat{\beta}^{\text{Cost}}}{\Delta s} = \frac{2{,}500 + 827}{2{,}500} = 1.33 \qquad (95\%\ \text{CI: } [1.24,\ 1.43]). \tag{18}$$

Relative to the mean pre-reform out-of-pocket payment of £6,592 (a mean gross cost of £11,592 for English ASHPs in the 12 months preceding October 2023 minus the £5,000 voucher), the £3,327 net price drop represents a 50.5% reduction in household upfront cost. The resulting arc price elasticity of adoption demand is

$$\hat{\varepsilon} = \frac{\widehat{\Delta Q}/Q}{\widehat{\Delta(p-s)}/(p-s)} = \frac{0.236}{-0.505} = -0.47 \qquad (95\%\ \text{CI: } [-0.69,\ -0.26]). \tag{19}$$

In the interacted model (Table 1, column 3, and Table 2, column 4), moving from mean competition ($A_m = 0$) to one standard deviation above the mean ($A_m = 1$) raises the proportional quantity response from 18.6% to 34.3%, increases the induced share σ from 0.157 to 0.256, raises household

pass-through $\hat{\rho}$ from 1.33 to 1.46, and increases the magnitude of the implied price elasticity by 68%, from -0.37 to -0.62.

6.4 MVPF and cost-per-tonne estimates

Appendix Table I.2 reports the resulting MVPF and public cost per tonne of CO_2e abated. In our headline specification (row 1, evaluating the £2,500 increment on the MCS engineering basis), the MVPF is 2.12 and the net government cost is £188/tCO_2e, well below the £265 central carbon value.

Local installer competition substantially improves the return on public spending. In Panel B of Appendix Table I.2, the MVPF rises from 1.92 at mean competition (row 2) to 2.51 at one standard deviation above mean competition (row 3), while the government cost per tonne falls by nearly 40%, from £229 to £139/tCO_2e. In equation (15), competition raises the calculated MVPF through the larger induced share of installations σ. Higher pass-through $\hat{\rho}$ is consistent with this stronger adoption response and increases households' out-of-pocket savings, but it does not enter the reported MVPF as a separate multiplicative adjustment to the statutory transfer Δs (since under standard incidence accounting, any deviation of pass-through from unity redistributes surplus between households and installers without altering the mechanical dollar value of the transfer unless differential welfare weights are applied to firm profits, as discussed in Hahn et al. 2024).

Panel C of Appendix Table I.2 explores sensitivity to the energy and fiscal-accounting assumptions. Replacing the MCS engineering energy block with the metered energy estimates of Bernard et al. (2024) in row (4) lowers the MVPF from 2.12 to 1.46 and raises the government cost per tonne from £188 to £416, above the £265 appraisal carbon value. Charging the pre-existing £5,000 voucher on induced installations to the policy in row (5) increases the outlay G from £2,500 to £3,454 per post-reform adopter, yielding an MVPF of 1.53 and a cost of £261/tCO_2e on the MCS engineering basis. Evaluating the entire £7,500 grant under an assumed induced share of $\sigma = 0.50$ gives an MVPF of 1.81 (£215/tCO_2e) on the MCS basis in row (6) and 1.23 (£477/tCO_2e) on the metered basis in Appendix Table I.3, row (4).

Appendix Table I.3 places these numbers alongside existing benchmarks. Our whole-grant metered estimate of 1.23 (£477/tCO_2e) at $\sigma = 0.50$ closely matches the preferred whole-grant estimate of 1.24 (£450/tCO_2e) reported by Bernard et al. (2024) for the same scheme under identical assumptions, confirming that the difference between our headline 2.12 and their 1.24 stems from evaluating the £2,500 increment rather than the full £7,500 grant and from using MCS engineering ratings rather than metered energy use. Relative to the US climate policies catalogued by Hahn et al. (2024), the BUS grant increase ranks above residential weatherization and appliance rebates (MVPF ≈ 1.0) and comparable to or above electric-vehicle subsidies (MVPF ≈ 1.5).

These welfare calculations are subject to three main caveats. First, the gap between MCS design ratings (68.4 tCO_2e) and metered consumption (30.9 tCO_2e) shifts the cost per tonne from below to above the UK appraisal carbon value, and reconciling the two would require linking MCS records to

household smart-meter data. Second, because roughly half of the headline invoice reduction reflects shifts toward smaller capacities and lower-cost models, the net out-of-pocket price drop overstates the pure price reduction for a fixed bundle. Third, the abatement calculation assumes every induced heat pump displaces a mains-gas condensing boiler. While natural gas heats the vast majority of British homes, replacing oil or direct electric heating would alter the emissions profile.

7 Conclusion

This paper shows that the effectiveness of demand-side subsidies for residential decarbonisation depends critically on the thickness of local installation markets. Exploiting the October 2023 increase in the Boiler Upgrade Scheme grant from £5,000 to £7,500 in England and Wales, with Scotland serving as an untreated comparison, we find that the higher grant raised monthly air-source heat pump installations in Northern England by 24%, generating roughly 7,200 additional installations over 20 post-reform months. At the same time, reported pre-grant installation costs fell by £827, implying an invoice-based pass-through rate to households of 1.33.

Both the quantity expansion and the cost decline are significantly larger in local labour markets that had less concentrated installer markets before the policy. While roughly half of the average cost decline reflects a shift toward smaller, higher-SCOP heat pumps and lower-cost models, pre-grant prices also fall by £206 within exact installer–model pairs at fixed capacity, and by an additional £169 per standard deviation of pre-policy local competition. Alongside a 45% rise in the number of active installers travelling in from outside the local TTWA and a 30% increase in average distance to installer headquarters, these patterns indicate that the subsidy expansion induced spatial market entry and intensified local competition.

For climate policy design, our results imply that consumer grants and local supply capacity are complements. Evaluating the £2,500 grant increment using MCS engineering fields yields a marginal value of public funds of 2.12 (at £188 per tonne of CO_2e), rising from 1.92 at mean installer competition to 2.51 in markets one standard deviation above the mean (where public cost drops to £139 per tonne). Uniform national demand subsidies therefore generate uneven adoption and welfare returns across space when local installer markets are thin, suggesting that supply-side policies targeting vocational training and trade entry can raise the return on capital grants.

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A Additional data construction details

A.1 Cleaning of technical and cost fields

The MCS extract contains an "overall cost" field and a "total installed capacity" field that are used to construct the price outcome, P_i, in addition to the main quantity outcomes. Three cleaning steps are applied before aggregation. First, reported zeros in cost and capacity are treated as missing. Second, we drop installations with cost above the 95^{th} percentile of the non-missing cost distribution (approximately £16,800) to remove outlier values, in addition to dropping installations with capacity outside the 1^{st} and 99^{th} percentiles. Third, cost is converted to constant 2023 GBP using the ONS annual CPI series (rebased to 2023 = 100) so that price estimates are directly comparable to the nominal £2,500 BUS grant increase. The price outcome reported in Section 5 is the resulting cleaned cost in 2023 pounds, estimated with and without installed capacity and installer × model controls as detailed in Table 2.

The reported cost is a gross measure of total installation cost rather than the net amount payable by the household. Under the BUS, the installer applies for the voucher and deducts its value from what the household pays, so the distinction matters for interpreting the price results. Three checks establish that the MCS field does not net the voucher out. First, the BUS took effect in England and Wales on 23 May 2022 and did not apply in Scotland. An England–Scotland difference-in-differences in reported cost at that launch, controlling for installed capacity, LSOA and year-month, gives $-£326$ (standard error 119), whereas mechanically netting a £5,000 voucher would give approximately $-£5,000$. Second, the English monthly cost series shows no step change at the launch date. Third, reported cost averages £1,675 per installed kW, which sits within the range for gross domestic installations. Were it net of the £7,500 grant, the implied gross figure would be £2,786 per kW, well outside that range. Price outcomes are therefore interpreted throughout as changes in the pre-grant invoice. We do not observe itemized cost components, financing terms, or payment timing.

A.2 Balanced-panel grid construction

For each geography (LSOA and TTWA), we build a complete area-by-month grid using the set of areas observed in the postcode lookup and the set of calendar months spanned by the microdata over the relevant period. Aggregated outcomes are merged into this grid. For count outcomes, unmerged cells are assigned zero. For means, unmerged cells correspond to area-months with no installations and therefore have undefined means. In the constructed dataset these cells are set to zero for convenience, but any analysis that uses means conditions on having at least one installation in the area-month.

A.3 Installer headquarters merges and recycled identifiers

The installer identifier in the MCS installation extract is the installation company's MCS number. The installer registry also reports installer identifiers and names. A small number of installer identifiers (19) are reused across time in the registry. For these cases, headquarters and certification information are merged using installer name rather than identifier, and the corresponding identifiers are excluded from identifier-based merges. The MCS registry does not include a unique, time-invariant firm identifier that resolves all such cases without using names.

A.4 Distance and off-site measures

For each installation with a successfully merged installer headquarters location and valid installation coordinates, we compute the great-circle (haversine) distance between the geolocated installation and headquarters coordinates, in kilometres. We define an installation as off-site if the installation TTWA differs from the installer's headquarters TTWA. We aggregate these measures to LSOA-month cells: mean distance, counts of distinct installers based inside and outside the TTWA, and the share of off-site installations. These measures are only defined for installations with valid coordinates and a successfully assigned headquarters location.

A.5 Certified and active installer counts

Certified installers in TTWA m during month τ are counted from the installer registry as those whose valid certification window includes the first day of the month. The registry does not report the intensity of activity within a certification spell. Active installers in LSOA i during month τ are defined as the number of distinct installers that completed at least one ASHP installation in LSOA i in month τ. Because this measure is constructed from installations, it mechanically co-moves with installation volumes. It is therefore interpreted as a descriptive measure of short-run participation rather than as an independent measure of capacity.

B Empirical strategy details

B.1 Month construction and event-time index

The time construction produces two indices used in estimation. The calendar index τ combines the calendar year and month. The event-time index rel_τ is the number of calendar months between τ and October 2023. It is integer-valued by construction and is used both for the sample window (months -36 to $+20$) and for the event-study specification in equation (8).

B.2 Competition measurement

Competition is based on installer concentration within TTWAs in a pre-policy period. For each TTWA m and installer j, let N_{jm} be the number of recorded installations in the pre-policy period. Installer shares are $s_{jm} = N_{jm} / \sum_{j'} N_{j'm}$. The inverse HHI is computed as in equation (4).

Two features of this construction are relevant for interpretation. First, HHI_m^{-1} is computed using installation shares, not counts of registered installers, so it captures the distribution of realised activity rather than the size of the installer registry. Second, because HHI_m^{-1} is computed from a pre-policy window, it is mechanically independent of post-policy outcomes, but it can still correlate with local demand fundamentals and with unobserved factors that shape the 2023 response. The main specifications absorb time-invariant TTWA characteristics via fixed effects and probe remaining concerns using alternative pre-period constructions of HHI_m^{-1} and controls for baseline adoption intensity.

The discretized competition index specification replaces A_m with an indicator for being in the top quartile of HHI_m^{-1} within the analysis sample. This specification does not impose linearity in the relationship between concentration and response.

B.3 Placebo and robustness designs

The diagnostic exercises use the same monthly framework and the same -36 to $+20$ month window as the main specification.

Placebo treated years are implemented by re-defining the treated-year indicator as a placebo year $y \in \{2018, 2019, 2021, 2022\}$ in place of 2023, keeping the event month fixed at October and using the same LSOA-month sample (Table C.5). This exercise tests for discontinuities in the same calendar month in years without the policy change.

Appendix Figure C.1 reports the dynamic competition interaction. Appendix Tables C.6–C.9 assess alternative competition windows, market-thickness measures, a matched-registry service-area definition, and overlap in the England–Scotland competition distributions.

B.4 Supply-side diagnostics and measurement limits

To probe spillovers and supply adjustment, we compute outcomes derived from linking installations to installer identifiers and headquarters locations.

The distance outcome is constructed at the installation level as the haversine distance between the installation postcode centroid and the installer headquarters coordinates, then aggregated to LSOA-month means. This variable is only observed for installations whose installer identifier can be matched to a headquarters location in the installer registry. LSOA-month cells with no matched installations have undefined means and therefore do not contribute to the distance regressions.

The off-site share is defined as the share of installations in an LSOA-month performed by installers whose headquarters TTWA differs from the installation TTWA. This outcome is undefined in LSOA-month cells with zero installations and, like the distance measure, is estimated on the subset of LSOA-month cells with at least one matched installation.

Installer participation is measured by two counts. The "active installers" count is the number of distinct installers with at least one ASHP installation in the LSOA-month, and the count of installers based outside the TTWA restricts this to installers whose registered headquarters lies in a different TTWA from the LSOA. Because both are constructed from installations, they are mechanically related to installation volumes and are treated as descriptive indicators of short-run market participation rather than as independent outcomes. The "certified installers" count used in Appendix C.1 is instead based on installer registry start and end dates for heat pump certification.

C Additional robustness and results

Table C.1: England–Scotland difference-in-differences estimates of the BUS effect on installations: full coefficient set

	(1)	(2)	(3)	(4)
BUS increase	0.212***	0.168***	0.171***	0.105**
	(0.045)	(0.045)	(0.044)	(0.052)
BUS increase × Competition			0.125**	
			(0.049)	
BUS increase × Top-quartile competition				0.289***
				(0.081)
Post-Oct 2023 × Competition			-0.036	
			(0.039)	
Post-Oct 2023 × Top-quartile competition				-0.272***
				(0.065)
Post-Oct 2023 × Pre-treatment HP installs		-0.022***	-0.022***	-0.023***
		(0.003)	(0.003)	(0.003)
BUS increase × Pre-treatment HP installs		0.001	0.002	0.003
		(0.004)	(0.004)	(0.004)
Time FE (monthly)	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes
Observations	740,544	740,544	740,544	740,544
AIC	422,051	420,691	420,629	420,646

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table reports the same specifications as Table 1, but includes the lower-order interaction terms ("Post-Oct 2023 × Competition/Top-quartile/Pre-treatment HP installs" and "BUS increase × Pre-treatment HP installs") that are omitted from the main-text table for brevity. The dependent variable, sample, fixed effects, clustering, and −36 to +20 month estimation window are identical to Table 1. Coefficients are log incidence-rate ratios from PPML.

Table C.2: Quantity response and the pre-policy number of active installers

	Count of ASHP installations (PPML)		
	(1)	(2)	(3)
BUS increase	0.171***	0.223***	0.224***
	(0.044)	(0.052)	(0.052)
BUS increase × Competition	0.125**		0.128***
	(0.049)		(0.049)
BUS increase × Active installers		0.161***	0.151**
		(0.058)	(0.059)
Time FE (monthly)	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes
Observations	740,544	740,544	740,544
AIC	420,629	420,639	420,581

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Coefficients from a Poisson fixed-effects regression of monthly ASHP installation counts at the LSOA-month level, estimated by PPML on the sample of Table 1. "Active installers" is the number of distinct installers with at least one heat pump installation in the TTWA over 2015–2021, per 1,000 residents, standardised across TTWAs so that the interaction reads per standard deviation like the competition index. Column (1) repeats column (3) of Table 1; column (2) replaces the competition index with the active-installer measure; column (3) includes both. All specifications include the pre-treatment HP installs control and LSOA, calendar year-month, and rural-LSOA-by-month fixed effects, with the lower-order interactions of each measure with the post indicator. The estimation window is months −36 to +20 around implementation. Standard errors (in parentheses) are clustered by LSOA.

Table C.3: BUS effect on installation cost: full coefficient set

	Heat-pump installation cost (OLS)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BUS increase	-757.824***	-448.144***	-152.184*	-826.665***	-527.953***	-206.463**	-121.347
	(120.539)	(108.934)	(88.117)	(122.227)	(110.576)	(90.614)	(94.761)
HP capacity		364.507***	323.732***		364.495***	323.880***	323.766***
		(5.202)	(14.689)		(5.200)	(14.685)	(14.689)
BUS increase × Competition				-333.072***	-251.132**	-168.577**	
				(111.225)	(100.610)	(75.111)	
BUS increase × Top-quartile competition							-191.346
							(141.342)
Post-Oct 2023 × Competition				252.504***	248.787***	156.143**	
				(96.959)	(87.133)	(65.996)	
Post-Oct 2023 × Top-quartile competition							198.651
							(125.423)
Post-Oct 2023 × Pre-treatment HP installs	15.722***	7.445*	-0.790	18.975***	10.710**	1.072	-0.231
	(5.053)	(4.127)	(3.045)	(5.522)	(4.518)	(3.080)	(3.076)
BUS increase × Pre-treatment HP installs	21.592***	22.568***	11.976***	18.185**	19.194***	10.069***	11.358***
	(6.931)	(6.341)	(3.805)	(7.331)	(6.608)	(3.828)	(3.831)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Installer × HP model FE			Yes			Yes	Yes
Observations	68,560	68,560	68,560	68,560	68,560	68,560	68,560
AIC	1,294,250	1,284,064	1,232,029	1,294,233	1,284,050	1,232,017	1,232,029

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table reports the same seven installation-level OLS specifications and the same 68,560-observation sample as Table 2, including the interaction coefficients omitted there. The dependent variable is reported installation cost in 2023 pounds across all heat pump types, cleaned as described in Appendix A.1. Column (1) is the baseline specification; column (2) adds installed capacity (kW); column (3) additionally includes installer × heat-pump-model fixed effects. Column (4) adds the continuous standardised inverse-HHI interaction without controlling for capacity; column (5) adds capacity; column (6) additionally includes installer × heat-pump-model fixed effects; column (7) replaces the continuous competition index in column (6) with the top-quartile indicator. Singleton installer–model pairs are retained. All columns include pre-treatment HP installs interactions and LSOA, calendar year-month, and rural-status-by-month fixed effects. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to +20 around October 2023.

Table C.4: Mechanisms: installer activity, spatial allocation, and system characteristics – full coefficient set

Panel A: Installer activity and spatial allocation								
	Active installers		Installers based outside the TTWA		Share of off-site installations		Distance to installer	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BUS increase	0.172***	0.177***	0.373***	0.392***	0.022*	0.037***	0.263***	0.288***
	(0.031)	(0.031)	(0.037)	(0.038)	(0.013)	(0.013)	(0.042)	(0.042)
BUS increase × Competition		0.105***		0.274***		0.025*		0.027
		(0.030)		(0.038)		(0.013)		(0.041)
Post-Oct 2023 × Competition		-0.042		-0.162***		-0.041***		-0.064*
		(0.026)		(0.033)		(0.011)		(0.035)
Post-Oct 2023 × Pre-treatment HP installs	-0.013***	-0.014***	-0.014***	-0.017***	-0.001*	-0.001***	-0.004**	-0.005**
	(0.002)	(0.002)	(0.003)	(0.003)	(0.001)	(0.001)	(0.002)	(0.002)
BUS increase × Pre-treatment HP installs	-0.005**	-0.005*	-0.005	-0.003	0.001**	0.002***	-0.001	-0.000
	(0.003)	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)	(0.002)	(0.003)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	738,777	738,777	618,450	618,450	44,491	44,491	44,491	44,491
AIC	384,272	384,245	276,971	276,881	37,903	37,875	142,292	142,286
Panel B: Characteristics of installed systems								
	HP capacity (kW)		SCOP		Flow temperature (°C)		Annual heating demand (kWh)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BUS increase	-0.570***	-0.595***	0.052***	0.046***	-0.540***	-0.444***	-549.448	-710.427
	(0.096)	(0.100)	(0.011)	(0.011)	(0.119)	(0.123)	(583.161)	(574.547)
BUS increase × Competition		-0.029		-0.010		0.063		-236.690
		(0.091)		(0.010)		(0.113)		(369.426)
Post-Oct 2023 × Competition		0.063		0.016**		-0.226**		414.964
		(0.077)		(0.007)		(0.096)		(257.889)
Post-Oct 2023 × Pre-treatment HP installs	0.009***	0.010***	0.000	0.001	-0.016***	-0.019***	41.768***	47.212***
	(0.003)	(0.003)	(0.000)	(0.000)	(0.005)	(0.006)	(10.727)	(12.055)
BUS increase × Pre-treatment HP installs	0.006	0.005	0.001**	0.001*	0.014**	0.017***	-8.503	-14.125
	(0.004)	(0.004)	(0.001)	(0.001)	(0.006)	(0.007)	(16.061)	(17.235)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Installer FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	68,560	68,560	68,029	68,029	68,029	68,029	68,560	68,560
AIC	333,844	333,846	13,109	13,103	344,991	344,967	1,604,518	1,604,522

* p < 0.1, ** p < 0.05, *** p < 0.01

Notes: This table reports the full coefficient sets for both panels of Table 3, including the post-by-competition, post-by-pre-treatment-installations, and BUS-increase-by-pre-treatment-installations interactions omitted there. Panel A uses LSOA-month outcomes: distinct active ASHP installers (columns 1–2), active installers headquartered outside the installation TTWA (columns 3–4), the off-site installation share (columns 5–6), and the log of mean installation-to-headquarters distance (columns 7–8). Columns 1–4 are estimated by PPML, dropping LSOAs with zero counts throughout the window; columns 5–8 are estimated by OLS on LSOA-months with geocoded installations and positive distances. Panel B reports installation-level OLS estimates for installed capacity, rated SCOP, design flow temperature, and annual heating demand on the cleaned cost sample, with installer fixed effects. In each panel, odd-numbered columns include pre-treatment HP installs interactions; even-numbered columns additionally include the continuous competition interaction. All specifications include LSOA, calendar year-month, and rural-status-by-month fixed effects. Samples match the corresponding main-table columns. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to +20 around October 2023.

Table C.5: England–Scotland placebo treated years (October placebo)

	(2018)	(2019)	(2021)	(2022)	(2023)
BUS increase	-0.092	0.097	0.014	-0.089	0.203***
	(0.092)	(0.084)	(0.058)	(0.064)	(0.047)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes
Observations	65,550	77,050	159,643	177,054	218,891
AIC	51,203	60,890	129,380	148,475	187,583

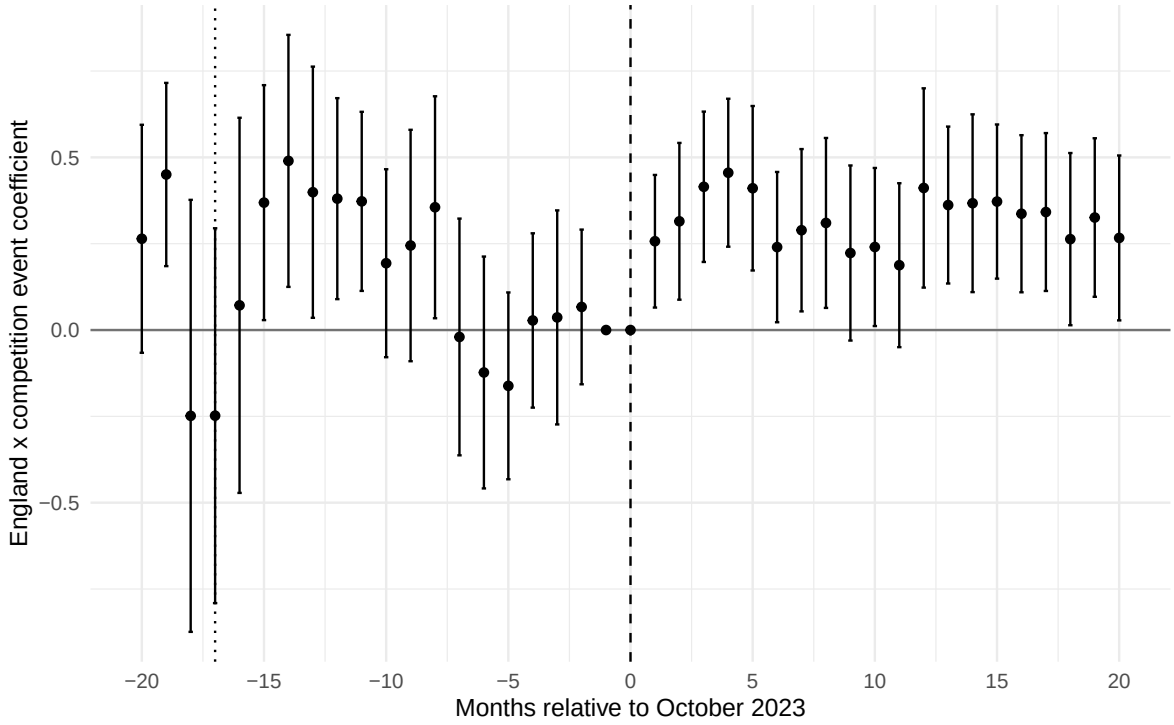
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The table estimates the baseline specification in equation (7) on placebo treatment years, keeping the event month fixed at October and defining the treated-year indicator as the placebo year shown in the column header. The dependent variable is the monthly count of ASHP installations at the LSOA level for Northern England and Scotland. All specifications include LSOA fixed effects and calendar year-month fixed effects, with standard errors clustered by LSOA. A BUS-increase estimate near zero is consistent with the absence of systematic discontinuities in October in years without the 2023 BUS policy change; for comparison, the matched 2023 estimate is 0.203 (significant at the 1% level).

C.1 Competition robustness

Figure C.1 reports the dynamic England–competition interaction around the BUS increase. Tables C.6–C.9 then assess the stability of the result to alternative competition windows, measures of market thickness, a matched-registry service-area definition, and overlap in the England–Scotland competition distributions. In Table C.9, restricting to the common-support sample preserves the continuous competition interactions on both costs and quantities as well as the top-quartile interaction on quantities and on capacity-adjusted costs without pair fixed effects. In column (4), which adds the demanding installer × heat-pump-model pair fixed effects to the top-quartile cost specification, the interaction point estimate (−£158) remains directionally consistent with the continuous within-pair estimate (−£160 in column 3) and the full-sample estimate (−£191 in Table 2, column 7), though with reduced precision given the restrictive within-pair absorption.

Figure C.1: Dynamic triple interaction on the effect of competition



Notes: The figure reports event-study coefficients from a Poisson fixed-effects regression of monthly ASHP installation counts at the LSOA level. The plotted points correspond to the interaction between an England indicator, standardised inverse HHI, and event-time indicators. The omitted reference months are event times −1 and 0. Error bars are 95 percent confidence intervals based on standard errors clustered by LSOA. Fixed effects and pre-treatment HP installs controls follow column (3) of Table 1. The model uses months −36 to 20 relative to October 2023; the figure displays months −20 to 20. The dashed line marks the BUS increase and the dotted line the initial BUS introduction in May 2022. Coefficients are in log-count units per standard deviation of competition.

Table C.6: Alternative pre-BUS HHI windows

	Count of ASHP installations (PPML)			
	2013–2017	2013–2015	2015–17	2015–19
BUS increase	0.143***	0.151***	0.160***	0.181***
	(0.045)	(0.045)	(0.045)	(0.046)
BUS increase × Competition	0.216***	0.212***	0.216***	0.189***
	(0.036)	(0.037)	(0.038)	(0.048)
Time FE (monthly)	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes	Yes
Observations	740,544	740,544	740,544	740,544
AIC	420,529	420,523	420,565	420,619

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The dependent variable is the monthly count of ASHP installations at the LSOA level, estimated by PPML. Each column replaces the competition measure in column (3) of Table 1 with inverse HHI constructed from the pre-BUS window shown. Installer shares use all heat pump installations within each TTWA; inverse HHI is standardised across TTWAs. The sample is held common across columns. All specifications include LSOA fixed effects, calendar year-month fixed effects, rural-LSOA-by-month fixed effects, and pre-treatment HP installs controls. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to 20 around implementation. Coefficients are log incidence-rate ratios.

Table C.7: Alternative market-thickness measures

	Count of ASHP installations (PPML)			
	Installer density	Entropy-effective installers	One minus CR4	Certified-HQ density
BUS increase	0.220***	0.160***	0.144***	0.178***
	(0.051)	(0.045)	(0.045)	(0.046)
BUS increase × Market thickness	0.128***	0.144***	0.105***	0.160***
	(0.046)	(0.053)	(0.038)	(0.042)
Time FE (monthly)	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes	Yes
Observations	740,544	740,544	740,544	740,544
AIC	420,648	420,607	420,561	420,562

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The dependent variable is the monthly count of ASHP installations at the LSOA level, estimated by PPML. Each column replaces inverse HHI with the standardised measure shown: log of one plus active installers per 1,000 residents; the exponential of Shannon entropy of installer shares; one minus the combined share of the four largest installers; and log of one plus certified installer headquarters per 1,000 residents. Activity measures use all heat pump installations in 2015–2021; certification is measured before the BUS increase. The sample is held common across columns. Fixed effects and pre-treatment HP installs controls follow column (3) of Table 1. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to 20 around implementation.

Table C.8: Alternative market definition: matched-registry service reach

	ASHP installation cost	Count of ASHP installations (PPML)
	(3)	(7)
BUS increase	-873.097***	0.112*
	(138.273)	(0.061)
HP capacity	364.818***	
	(5.274)	
BUS increase × Competition	-585.964***	0.216***
	(120.811)	(0.059)
Time FE (monthly)	Yes	Yes
LSOA FE	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes
Pre-treatment HP installs	Yes	Yes
Observations	67,140	716,490
AIC	1,257,621	409,880

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: This table reports the specifications in column (5) of Table 2 and column (3) of Table 1, replacing inverse HHI with the standardised number of matched installers whose service radius reaches the TTWA centroid. Each radius is the 90$^{\text{th}}$ percentile of headquarters-to-installation distances in 2015–2021, capped at 150 km. The sample is held common across alternative geographic definitions. The first column reports OLS estimates for installation cost in pounds across all heat pump types, controlling for installed capacity; the second reports PPML estimates for monthly ASHP installation counts. Fixed effects and pre-treatment HP installs controls follow Tables 2 and 1. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to 20 around implementation.

Table C.9: Competition effects within England–Scotland common support

	Cost: no pair FE (OLS)		Cost: pair FE (OLS)		ASHP installations (PPML)	
	(1)	(2)	(3)	(4)	(5)	(6)
BUS increase	-479.055***	-248.616*	-178.439*	-108.392	0.160***	0.090*
	(118.600)	(127.381)	(98.151)	(100.473)	(0.047)	(0.054)
HP capacity	370.533***	370.367***	319.613***	319.511***		
	(5.633)	(5.631)	(15.744)	(15.753)		
BUS increase × Competition	-195.696*		-160.390*		0.118*	
	(118.610)		(84.558)		(0.061)	
BUS increase × Top-quartile competition		-847.145***		-157.844		0.228***
		(206.680)		(154.568)		(0.087)
Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes	Yes	Yes
Installer × HP model FE			Yes	Yes		
Pre-treatment HP installs	Yes	Yes	Yes	Yes	Yes	Yes
Observations	57,676	57,676	57,676	57,676	620,217	620,217
AIC	1,081,164	1,081,126	1,037,109	1,037,115	354,913	354,869

* p < 0.1, ** p < 0.05, *** p < 0.01

Notes: The sample is restricted to the intersection of the England and Scotland 1st–99th percentile ranges of standardised inverse HHI, retaining 10,881 of 12,992 LSOAs (83.8 percent). The competition index and pooled quartiles are defined before the restriction. Columns (1)–(4) report installation-level OLS estimates for reported installation cost in 2023 pounds across all heat pump types, using the same 57,676 installations and controlling for installed capacity (kW). Columns (1) and (3) use the continuous competition index; columns (2) and (4) use its top-quartile indicator. Columns (1)–(2) allow installer/model composition to vary; columns (3)–(4) additionally include installer × heat-pump-model fixed effects, retaining singleton pairs, to estimate within-pair cost responses conditional on capacity. Columns (1), (3), and (4) correspond to columns (5), (6), and (7) of Table 2; column (2) is the top-quartile counterpart of column (1). Columns (5)–(6) report PPML estimates for monthly ASHP installation counts using continuous and top-quartile competition, respectively, corresponding to columns (3)–(4) of Table 1. All specifications include pre-treatment HP installs interactions and LSOA, calendar year-month, and rural-status-by-month fixed effects. Standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to +20 around October 2023.

D Installer learning and installation cost

We test whether reported installation costs decline as installers accumulate experience with a specific heat pump model, using the full history of MCS-certified ASHP installations in England, Wales, and Scotland. Let $N_{jh\tau}$ denote the number of installations completed by installer j using heat pump model h in calendar month τ. We define installer–model experience at the start of month t as

$$E^P_{jht} = \sum_{\tau<t} N_{jh\tau}, \tag{20}$$

excluding installations in the current month t. We analogously define installer j's prior experience with other heat pump models, $E^I_{jht} = \sum_{\tau<t} \sum_{h'\neq h} N_{jh'\tau}$, and industry-wide experience with model h accumulated by other installers, $E^M_{jht} = \sum_{\tau<t} \sum_{j'\neq j} N_{j'h\tau}$.

For installation i, completed by installer j using model h in month $t(i)$, we estimate

$$\begin{aligned}\log C_i = {} & \beta_P \log(1+E^P_{jht}) + \beta_I \log(1+E^I_{jht}) + \beta_M \log(1+E^M_{jht}) + \rho \log K_i \\ & + \alpha_j + \gamma_h + \mu_{g(i)} + \lambda_{t(i)} + \psi_{c(i)y(i)} + \xi B_i + \varepsilon_i,\end{aligned} \tag{21}$$

where C_i is reported gross installation cost, K_i is installed capacity, $g(i)$ is the installation TTWA, and B_i is the England-and-Wales post-October 2023 BUS-increase indicator. Columns (1)–(3) include additive installer (α_j) and model (γ_h) fixed effects alongside TTWA, calendar year-month, and country-by-year fixed effects. Column (3) adds the log age of the installer–model relationship and current monthly installer–model volume, and column (4) replaces the additive firm and product effects with interacted installer-by-model fixed effects. Standard errors are two-way clustered by installer and heat pump model.

Table D.1 shows no evidence that repeated installation of the same heat pump model lowers reported project costs: the coefficient on $\log(1+E^P_{jht})$ lies between -0.003 and 0.000 and is statistically indistinguishable from zero across all four specifications. Prior experience with other models ($\log(1+E^I_{jht})$) carries a small negative coefficient of -0.009 to -0.010 ($p<0.05$) in columns (2) and (3), implying a 0.6–0.7% cost reduction for a doubling of general experience, and contemporaneous monthly volume has a coefficient of -0.010 ($p<0.01$) in column (3), but the general-experience effect shrinks to -0.003 (insignificant) once installer-by-model fixed effects are included in column (4). Cross-installer spillovers ($\log(1+E^M_{jht})$) are near zero throughout.

Table D.1: Installer experience and reported ASHP installation cost

	ASHP installation cost (log)			
	(1)	(2)	(3)	(4)
Installer × HP model experience (log)	-0.003	-0.002	-0.002	0.000
	(0.002)	(0.002)	(0.002)	(0.002)
Installer experience with other models (log)		-0.009**	-0.010**	-0.003
		(0.004)	(0.004)	(0.003)
Other installers' experience with HP model (log)		-0.000	-0.001	-0.006
		(0.003)	(0.003)	(0.005)
Months since installer first used HP model (log)			0.003	
			(0.002)	
Current installer × HP model volume (log)			-0.010***	
			(0.003)	
HP capacity (log)	0.265***	0.264***	0.263***	0.250***
	(0.021)	(0.021)	(0.021)	(0.028)
Time FE (monthly)	Yes	Yes	Yes	Yes
TTWA FE	Yes	Yes	Yes	Yes
Installer FE	Yes	Yes	Yes	
HP model FE	Yes	Yes	Yes	
Installer × HP model FE				Yes
Country × Year FE and BUS increase control	Yes	Yes	Yes	Yes
Observations	216,686	216,686	216,686	200,694
AIC	-95,080	-95,255	-95,461	-148,086

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The dependent variable is the log of total reported installation cost. The estimation sample includes ASHP installations in England, Wales, and Scotland with non-missing cost, capacity, installer, heat pump model, and TTWA, after excluding observations above the 95^{th} percentile of reported cost. Experience is measured using installations completed before the current calendar month. Columns (1)–(3) include additive installer and heat-pump-model fixed effects; column (4) includes installer-by-model fixed effects. All specifications include TTWA, calendar year-month, and country-by-year fixed effects, control for installed capacity and the BUS increase, and report standard errors two-way clustered by installer and heat pump model.

E Installer capacity and the quantity response

We next test whether the stronger quantity response in less concentrated TTWAs simply proxies for greater pre-existing spare throughput capacity. Because the MCS registry does not record firm staffing or maximum output, we construct two proxy measures of pre-policy capacity headroom from observed monthly installation peaks over the 36 pre-reform months. Let $Q_{m\tau}$ denote ASHP installations in TTWA m in month τ, and let $\overline{Q}_{m,-12}$ denote the mean monthly count over the 12 months preceding October 2023. Our TTWA-peak headroom measure is

$$K_m^T = \max_{\tau \in \{-36,\ldots,-1\}} Q_{m\tau}, \qquad H_m^T = \log\left(\frac{K_m^T + 1}{\overline{Q}_{m,-12} + 1}\right). \tag{22}$$

Across TTWAs, the median pre-policy peak is 26 installations per month and the median level difference $K_m^T - \overline{Q}_{m,-12}$ is 15.25 installations.

Our second measure is built from installer-level national peaks. Let $N_{j\tau}$ denote installer j's total ASHP installations across Great Britain in month τ, with pre-policy peak $K_j = \max_{\tau \in \{-36,\ldots,-1\}} N_{j\tau}$. Allocating each installer's peak across TTWAs using its pre-policy market shares ω_{jm} gives

$$K_m^I = \sum_j \omega_{jm} K_j, \qquad H_m^I = \log\left(\frac{K_m^I + 1}{\overline{Q}_{m,-12} + 1}\right), \tag{23}$$

which has a median peak of 41.33 installations per month and median headroom of 32.30 installations. Both H_m^T and H_m^I are standardised across TTWAs and added alongside A_m in the interacted PPML specification:

$$\mathbb{E}[Y_{i\tau} \mid \cdot] = \exp\left\{\alpha_i + \lambda_\tau + \rho_{r(i),e(\tau)} + \beta E_i P_\tau + \delta E_i P_\tau A_{m(i)} + \kappa E_i P_\tau H_{m(i)}^k + X_{i\tau}'\Gamma\right\}. \tag{24}$$

Table E.1 shows that conditioning on revealed throughput headroom does not attenuate the competition gradient. The TTWA headroom interaction is negative in columns (2) and (3) (-0.101 and -0.079), while the installer-peak headroom interaction in column (4) is -0.001 (s.e. $= 0.041$). In both joint specifications, the competition interaction remains virtually unchanged at 0.138 (column 3) and 0.133 (column 4), significant at the 1% level.

Table E.1: Pre-policy installer capacity and the BUS quantity response

	Count of ASHP installations (PPML)			
	(1)	(2)	(3)	(4)
BUS increase	0.171***	0.222***	0.252***	0.337***
	(0.044)	(0.050)	(0.051)	(0.054)
BUS increase × Competition	0.125**		0.138***	0.133***
	(0.049)		(0.052)	(0.049)
BUS increase × TTWA capacity headroom		-0.101***	-0.079**	
		(0.033)	(0.035)	
BUS increase × Installer capacity headroom				-0.001
				(0.041)
Time FE (monthly)	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes	Yes
Observations	740,544	740,544	740,544	740,544
AIC	420,629	420,214	420,179	420,125

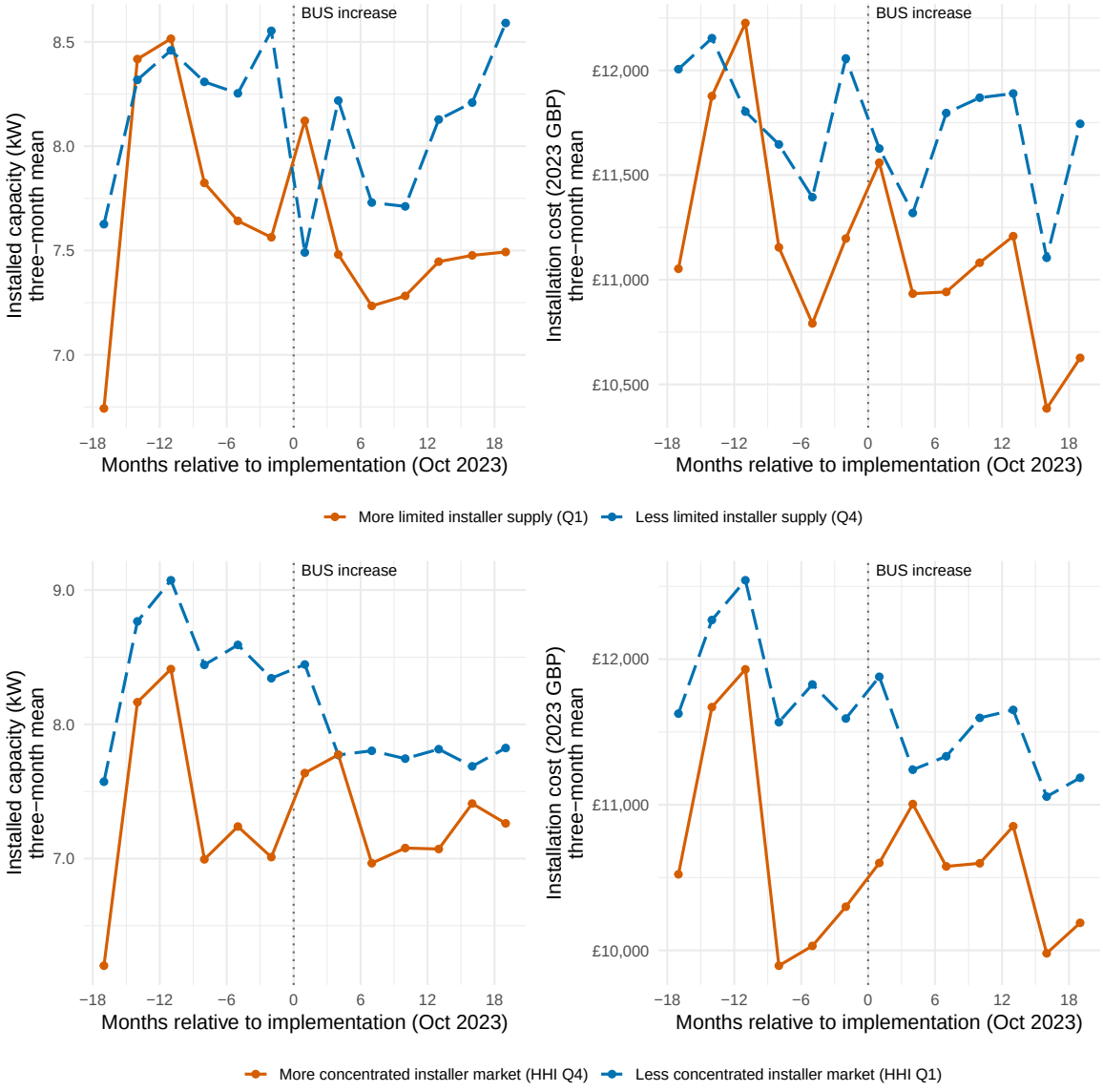
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The dependent variable is the monthly count of ASHP installations at the LSOA level. Capacity is measured over the 36 months before October 2023. TTWA capacity is the highest monthly ASHP count observed in the installation TTWA. Installer capacity is each installer's highest total monthly ASHP count, allocated across the TTWAs it served using its pre-policy installation shares. Headroom is the log ratio of revealed capacity to mean monthly installations over the final 12 pre-policy months, with one added to both terms, and is standardised across TTWAs. All specifications include LSOA, calendar year-month, and rural-LSOA-by-event-month fixed effects and control for pre-treatment HP installations. Standard errors (in parentheses) are clustered by LSOA. The estimation window runs from 36 months before to 20 months after implementation.

F Installed capacity and cost by pre-policy installer supply

Figure F.1 plots unadjusted three-month means of installed thermal capacity (kW) and reported gross installation cost (in 2023 pounds) in Northern England across the top and bottom quartiles of two pre-policy TTWA supply measures: active installers per 1,000 residents (top row) and raw installer HHI (bottom row, where Q4 is most concentrated). Installed capacity declines after October 2023 across both tails of each distribution, confirming that the move toward smaller systems is not confined to thin or concentrated markets.

Figure F.1: Installed capacity and cost by pre-policy installer supply



Notes: Each point is the installation-level mean within a non-overlapping three-month period, aligned so that no period crosses the October 2023 BUS increase. The sample contains ASHP installations in Northern England with non-missing cleaned capacity and cost, after excluding costs above the 95$^{\text{th}}$ percentile. Reported costs are in 2023 pounds. Installer-supply and HHI quartiles are computed at the TTWA level from 2015–2021 installations. The figure covers months −18 to 20 relative to implementation.

G Additional figures and tables from the main analysis

Figure G.1: Representative MCS installation record

MCS Installation Record

Installation

Commission date	Postcode	MPAN
2025-04-01	CF62 8BX	2199992432790

System & outcomes

Type	Capacity (kW)	Annual heating demand (kWh)	Installation cost (£)
Air Source Heat Pump	14	13,567	9,760.05

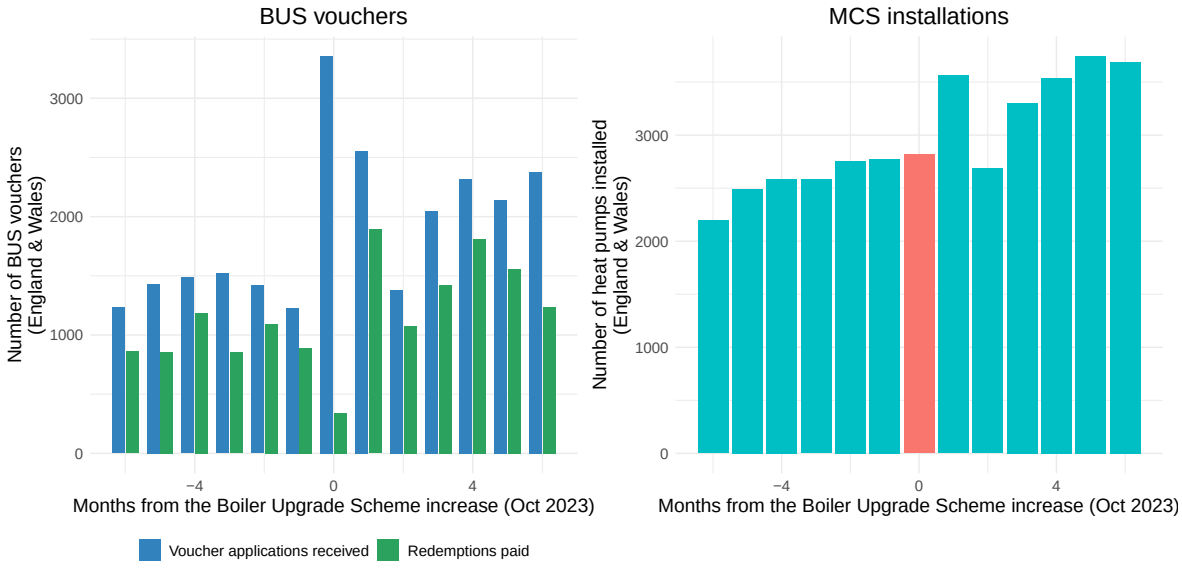
Installer & product

Installer	Product ID	MCS product number	Product name
Octopus Energy Services Limited	63565	EDLA14DA3V3	EDLA14D(3)V3

Licence holder	Flow temp	SCOP
Daikin Europe N.V.	50°C	3.60

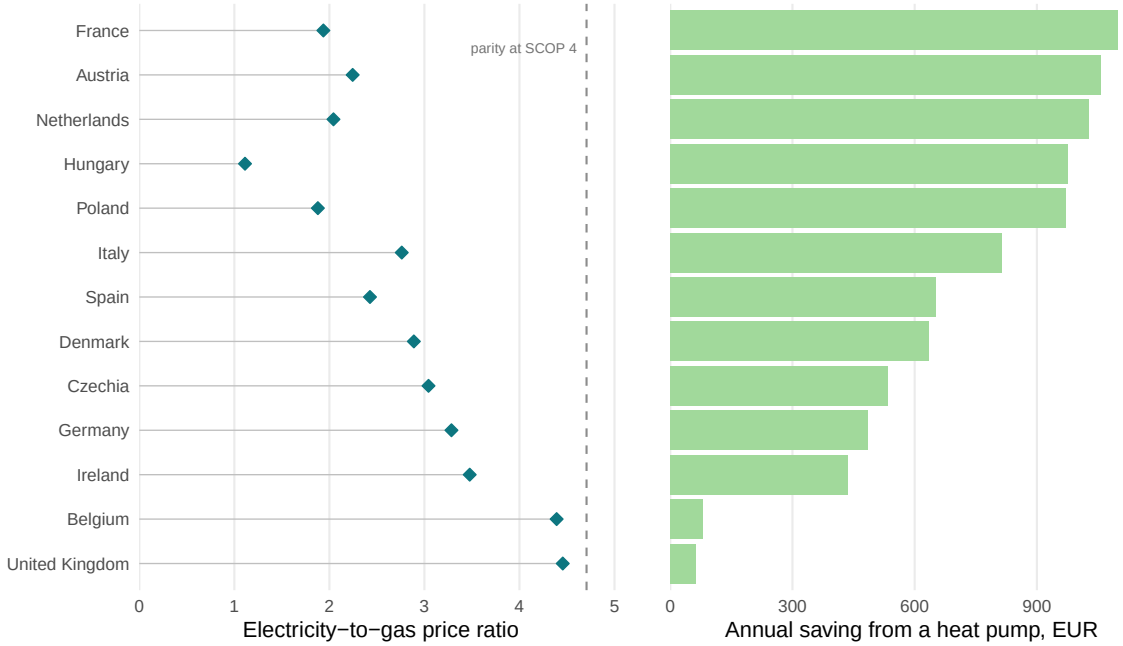
Notes: The figure reproduces a representative MCS installation record to illustrate the fields available in the administrative data. The record shown is a real commissioned installation; MPAN and postcode are illustrative. The "installation cost" field is the key price outcome used in the analysis and is recorded inclusive of the BUS grant. The "annual heating demand" and "SCOP" fields are used in external-cost calculations but are not the primary outcomes of the empirical design.

Figure G.2: Monthly BUS voucher redemptions and ASHP installations in England and Wales



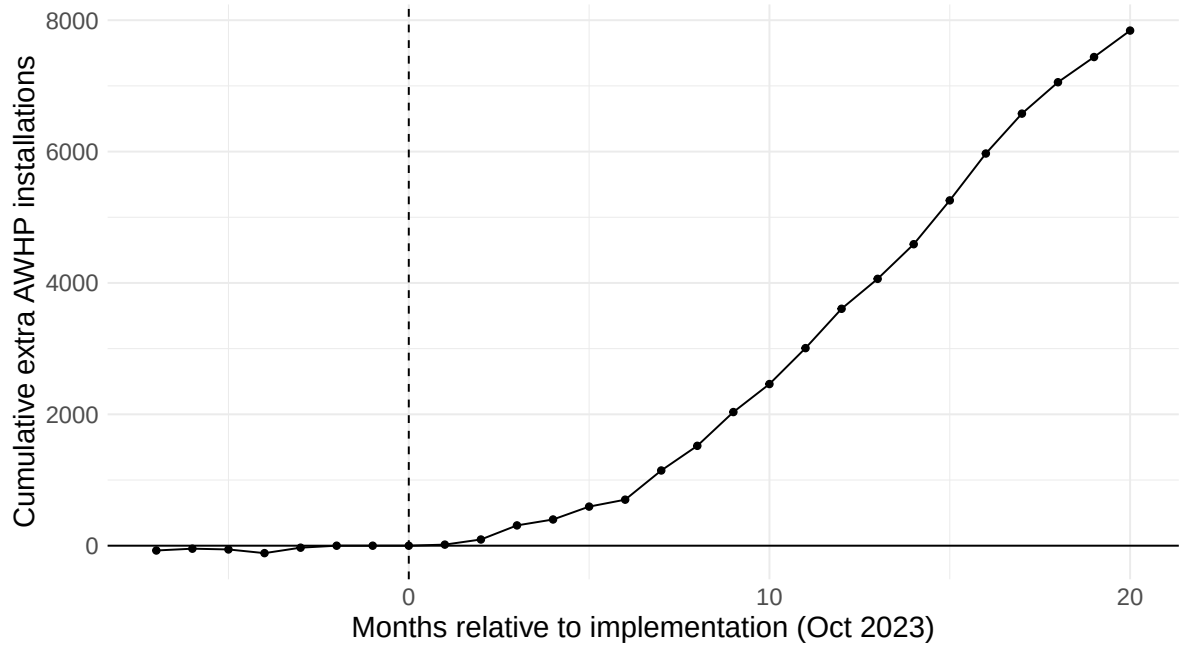
Notes: The figure plots monthly BUS voucher redemptions (left axis) and total MCS-recorded ASHP installations in England and Wales (right axis). Month 0 is October 2023, the date of the BUS grant increase. The close co-movement of the two series confirms that the MCS administrative records capture the timing of the policy change. Divergences between the two series can arise from: installations that do not claim a BUS voucher (e.g. self-funded), commissioning months that differ from voucher-redemption months, and small differences in ASHP technology scope between the two administrative sources.

Figure G.3: Heat pump running-cost parity in the UK



Notes: The figure compares the running costs of an air-source heat pump with those of a gas boiler in the UK, using prevailing electricity and gas tariffs. Running costs are estimated on the basis of a typical household heating demand and reflect the efficiency advantage of heat pumps (SCOP) against the electricity–gas price ratio. Periods where the heat pump line lies above the gas boiler line indicate that the heat pump incurs higher annual fuel bills despite its higher efficiency.

Figure G.4: Cumulative additional ASHP installations in England relative to Scotland



Notes: The figure plots the cumulative sum of the monthly England–Scotland event-study coefficients from equation (8), starting from the first post-implementation month. Each point represents cumulative additional ASHP installations in England relative to Scotland, expressed as a proportion of the pre-implementation baseline. The shaded band is a 95 percent confidence interval based on standard errors clustered by LSOA. The specification includes LSOA fixed effects, calendar year-month fixed effects, and rural-LSOA-by-month fixed effects.

Table G.1: Distance to installer and off-site installation at the installation level

	log(distance to installer)		Off-site installation (0/1)	
	(1)	(2)	(3)	(4)
BUS increase	0.271***	0.288***	0.026**	0.039***
	(0.042)	(0.042)	(0.013)	(0.013)
BUS increase × Competition		0.014		0.021
		(0.042)		(0.013)
Time FE (monthly)	Yes	Yes	Yes	Yes
LSOA FE	Yes	Yes	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes	Yes	Yes
Pre-treatment HP installs	Yes	Yes	Yes	Yes
Observations	60,085	60,085	60,085	60,085
AIC	185,130	185,128	45,291	45,265

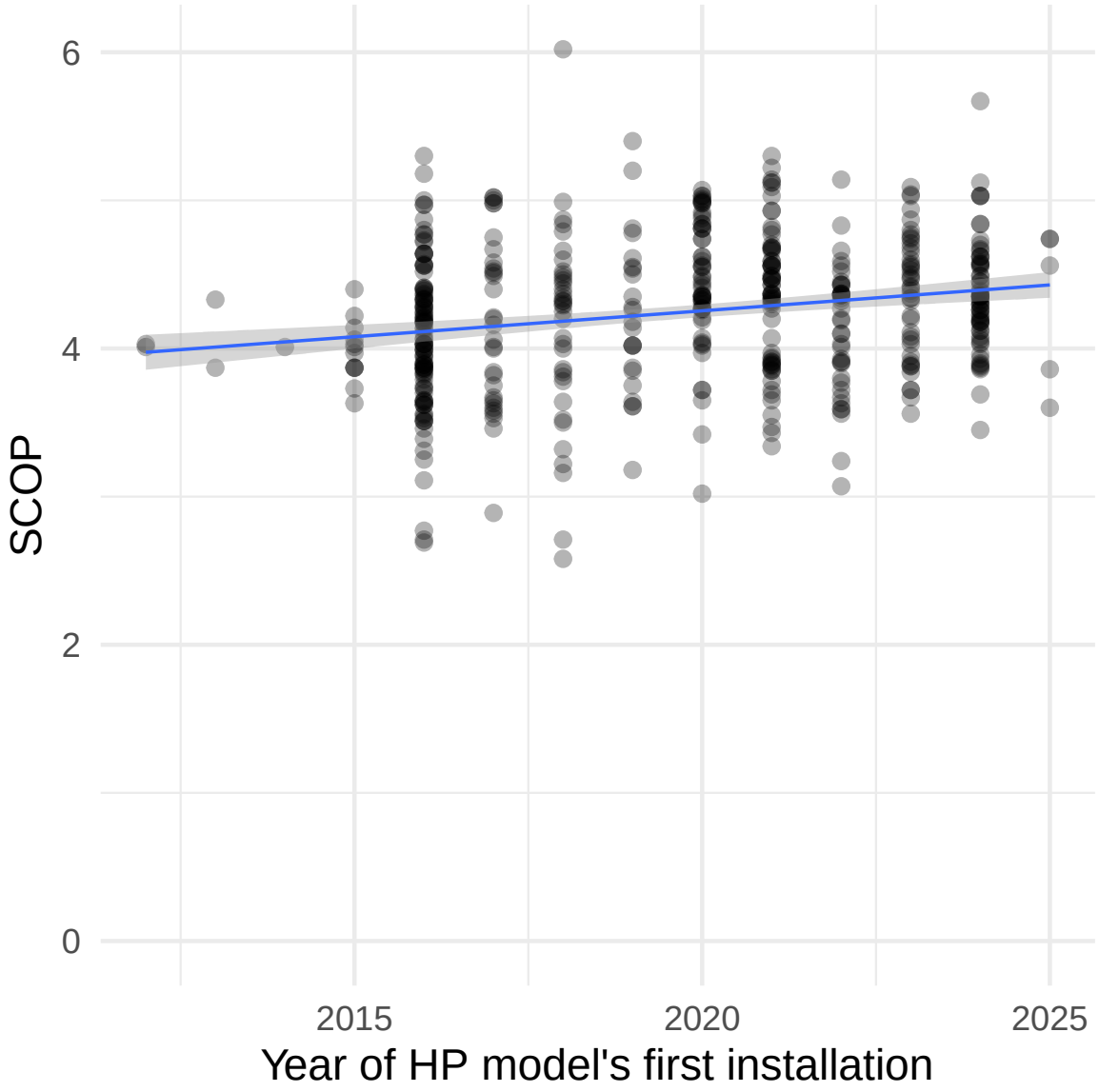
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: One observation per ASHP installation in the Table 1 geography and window whose installer has a geocoded registered headquarters. Columns (1)–(2): the log of the straight-line distance between the installation postcode centroid and the installer headquarters. Columns (3)–(4): an indicator for the headquarters lying outside the installation's TTWA ("off-site"), estimated as a linear probability model, so coefficients are changes in the share. Odd columns report the England–Scotland specification with the pre-treatment HP installs control; even columns add the competition interaction. LSOA, calendar year-month and rural-LSOA-by-month fixed effects as in Table 2; standard errors (in parentheses) are clustered by LSOA. The estimation window is months −36 to +20 around implementation. These are the installation-level counterparts of columns (5)–(8) of Table 3, Panel A, which aggregate the same two variables to the LSOA-month.

H heat pump quality and new installer characteristics

Figure H.1 plots mean seasonal coefficient of performance (SCOP) for commissioned ASHP installations by year, providing evidence on whether the BUS increase was associated with changes in the quality of installed systems.

Figure H.1: Mean SCOP of commissioned ASHP installations by year



Notes: The figure plots the mean seasonal coefficient of performance (SCOP) of commissioned ASHP installations recorded in the MCS dataset, by calendar year. SCOP is a rated efficiency measure reported for each installation in the MCS records. Higher SCOP indicates greater thermal efficiency. The figure assesses whether the BUS increase was accompanied by a detectable shift in the efficiency of installed systems.

Table H.1: Characteristics of new installers entering after the BUS increase, by SCOP quartile

	SCOP	
	(1)	(2)
New installer in TTWA × BUS increase	0.135***	0.131***
	(0.012)	(0.013)
New installer in TTWA	-0.102***	-0.099***
	(0.011)	(0.011)
New installer in TTWA × Competition		0.007
		(0.007)
Time FE (monthly)	Yes	Yes
LSOA FE	Yes	Yes
Rural LSOA × Time FE (monthly)	Yes	Yes
Observations	68,036	68,036
AIC	45,047	45,047

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: The table compares the characteristics of installers that first appear in the MCS installation data after October 2023 (new entrants) with those of installers active before the BUS increase, broken down by the mean SCOP quartile of systems installed. The table assesses whether new entrants are associated with systematically different installation quality than incumbents.

I Marginal value of public funds: inputs and results

This appendix collects the tables underlying the marginal-value-of-public-funds calculation in Section 6. Table I.1 reports the inputs: the per-installation energy and abatement block computed from the MCS records, the behavioural parameters derived from the difference-in-differences estimates, and the appraisal parameters. Table I.2 reports the resulting MVPF and government cost per tonne under each evaluation, and Table I.3 compares them with estimates in the literature.

Table I.1: Inputs to the marginal value of public funds calculation

Panel A: Energy and emissions per air-source installation (MCS records)	
Annual heat delivered, Q (kWh)	16,709
Rated seasonal coefficient of performance, SCOP	3.71
Annual electricity use, E (kWh)	4,517
Annual gas displaced, Gas (kWh)	19,658
Lifetime abatement, T (tCO_2e, 2023–2043)	68.4
Discounted climate benefit, V^{CO_2} (£)	14,849
Discounted air-quality benefit, V^{AQ} (£)	520
Discounted change in energy spending (£)	−1,647
Panel B: Behavioural response to the £2,500 increase (Section 5)	
Quantity response, $\exp(\hat{\beta}) - 1$	0.236
per £1,000 of grant	0.094
Change in reported installation cost (£)	−827
Pass-through to households, $\hat{\rho}$	1.33
Pre-increase out-of-pocket price (£)	6,592
Demand elasticity, $\hat{\varepsilon}$	−0.47
Induced share of installations, σ	0.191
Panel C: Policy and appraisal parameters	
Baseline installed cost, gross of grant (£)	11,639
Avoided gas-boiler capital cost (£)	2,250
Carbon value, 2023 (£ / tCO_2e)	265
Net fiscal externality per induced installation, F (£)	273
Discount rate (social / health / household)	3.5% / 1.5% / 5%

Notes: Panel A reports means over the 24,170 English air-source installations commissioned in the 20 months after implementation with a usable SCOP and heat-demand record, computed from equations (16) and (17) with a counterfactual boiler efficiency of $\eta = 0.85$. Monetary flows are discounted over 2023–2043. Panel B derives from column (1) of Table 1 and the cost decomposition in Section 5.3; costs are expressed in 2023 pounds. The net fiscal externality in Panel C combines forgone VAT on the avoided gas boiler, VAT on the change in household energy spending, emissions-trading receipts on additional grid electricity, and the United Kingdom's share of global climate damages. Emission factors and carbon values follow Department for Energy Security and Net Zero (2023); discount rates follow HM Treasury (2022).

Table I.2: Marginal value of public funds of the October 2023 BUS increase

	Evaluation	Transfer (£)	$\hat{\rho}$	σ	MVPF	Govt. cost (£/tCO$_2$e)
Panel A: Headline — the £2,500 increase						
(1)	Baseline	2,500	1.33	0.191	2.12	188
Panel B: By pre-policy installer competition						
(2)	At mean competition	2,500	1.33	0.157	1.92	229
(3)	At +1 s.d. of competition	2,500	1.46	0.256	2.51	139
Panel C: Sensitivity						
(4)	Metered energy basis	2,500	1.33	0.191	1.46	416
(5)	Full fiscal cost of induced installs	2,500	1.33	0.191	1.53	261
(6)	Whole grant, assumed $\sigma = 0.50$	7,500	1.33	0.500	1.81	215

Notes: Each row applies equation (15) with the inputs of Table I.1. "Transfer" is the subsidy change being evaluated; $\hat{\rho}$ is pass-through to households from equation (18); σ is the share of post-implementation installations induced. "Govt. cost" is the incremental public outlay per induced installation divided by lifetime abatement. Row (1) is the headline specification: abatement from the MCS engineering fields, and the policy costed at the £2,500 increment. Rows (2) and (3) evaluate the interacted specification of Table 1 at the mean and at one standard deviation above the mean of the competition index, with the cost response taken from the corresponding decomposition components. Panel C varies the two assumptions the headline rests on. Row (4) replaces the MCS energy block of Table I.1, Panel A, with the metered estimates of Bernard et al. (2024). Row (5) retains the MCS engineering energy block of Row (1) but charges to the policy the pre-existing £5,000 voucher paid on installations the increase induced, raising the incremental outlay per post-implementation adopter from £2,500 to £3,454. Row (6) evaluates the full £7,500 grant at an assumed induced share of 0.50 and is reported for comparability only, since the design identifies σ for the increment alone.

Table I.3: Comparison with marginal-value-of-public-funds estimates in the literature

	Evaluation	Transfer evaluated	Energy basis	MVPF	Govt. cost (per tCO_2e)
Panel A: This paper (Boiler Upgrade Scheme, England vs. Scotland)					
(1)	Increment, headline	£2,500	MCS design	2.12	£188
(2)	Increment, metered energy	£2,500	metered	1.46	£416
(3)	Whole grant, $\sigma = 0.50$	£7,500	MCS design	1.81	£215
(4)	Whole grant, $\sigma = 0.50$	£7,500	metered	1.23	£477
Panel B: Bernard et al. (2024), same scheme					
(5)	Whole subsidy, 50% marginal	£7,500	metered	1.24	£450
(6)	Whole subsidy, 25% marginal	£7,500	metered	1.12	£906
(7)	First £1 of subsidy	marginal	metered	2.77	—
(8)	Whole subsidy, with learning	£7,500	metered	1.90	—
Panel C: Hahn et al. (2024), US climate policies					
(9)	Wind PTC, residential solar	—	—	> 2	—
(10)	Electric vehicle subsidies	—	—	≈ 1.5	—
(11)	Appliance rebates, weatherization	—	—	≈ 1	—
(12)	Fuel taxes, cap and trade	—	—	< 0.7	—

Notes: Panel A reproduces rows of Table I.2 together with one additional combination, row (4), that aligns both conventions with Panel B. "Transfer evaluated" is the subsidy change the ratio is computed for; "energy basis" is whether abatement per installation comes from the MCS engineering fields (68.4 tCO_2e) or from metered consumption (30.9 tCO_2e). Panel B reports Table 4 of Bernard et al. (2024) at a 3.5% discount rate, row (5) being their preferred specification; row (7) is their marginal MVPF evaluated at the first pound of subsidy, and row (8) adds learning-by-doing benefits under an assumed gas-boiler learning rate. Panel C reports category values for US policies, which use a dollar social cost of carbon and different counterfactuals; they indicate magnitude rather than being directly comparable in levels. Government cost per tonne is omitted where the source does not report it on a comparable basis.

J Determinants of local installer competition: technical details and robustness

Specification curve. Figure J.1 examines the sensitivity of the five Lasso-selected covariates across 47 variations on the baseline LSOA specification, plotting point estimates and 95% TTWA-clustered confidence intervals. The three supply-side variables and population density maintain their sign and statistical significance across nearly the entire curve: the 95% confidence interval excludes zero in 43 of 46 specifications for the plumber wage index (93%), 42 of 47 for construction self-employment (89%), and 38 of 45 for distance to the nearest heat pump training centre (84%). Long-term mean temperature, by contrast, is statistically significant in only two specifications and changes sign in four.

The 47 variations span six families: (i) *Unit of analysis*: estimating the model on the 155 TTWA means (unweighted and weighted by LSOA counts), with covariates re-standardised at the TTWA level, (ii) *Region fixed effects*: adding fixed effects for the nine English statistical regions (plus a tenth category for English LSOAs in cross-border Welsh TTWAs), (iii) *Sample restrictions*: dropping the London TTWA (4,600 LSOAs) or the six Anglo-Scottish border TTWAs, (iv) *Covariate subsets*: dropping each of the 18 candidate covariates one at a time, plus four block drops (dropping the climate pair, the market-size pair, all demand variables, or all non-selected supply variables), (v) *Proxy swaps*: replacing individual covariates with alternative measures of the same concept (the all-employee TTWA median wage for the synthetic plumber wage, counts of training centres within 25 km or per 100,000 residents for training distance, local employment for business-site counts, a rural dummy for population density, and Liberal Democrat or Brexit Party vote shares as placebos for the Green vote share), and (vi) *Outcome definitions*: replacing A_m with inverse HHI computed on untrimmed installations, $\log(\mathrm{HHI}_m^{-1})$, sign-reversed raw HHI, and the sign-reversed four-firm concentration ratio (CR_4).

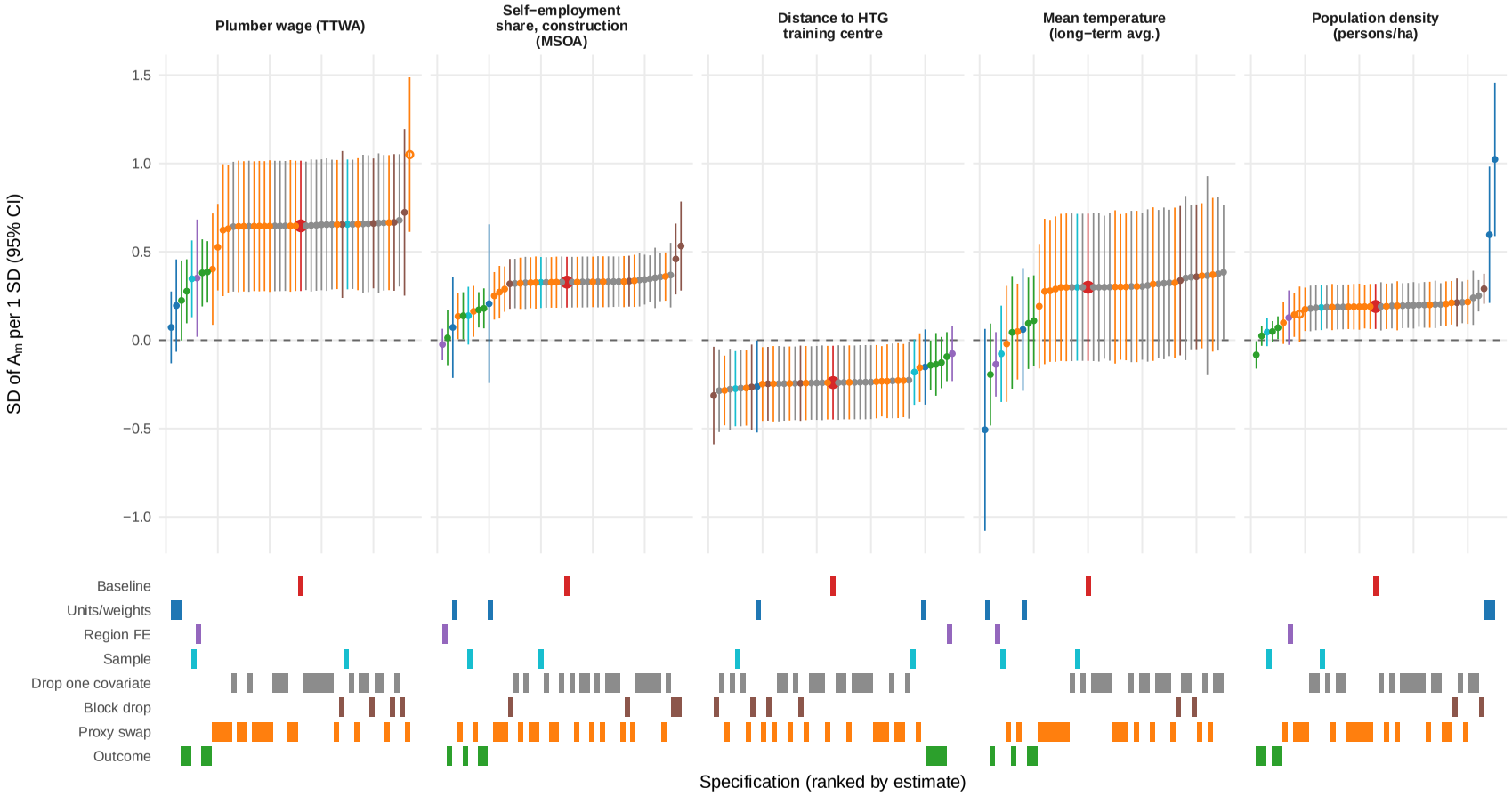


Figure J.1: Specification curve for the five Lasso-selected covariates. Each panel plots the coefficient on one covariate, with 95 percent confidence intervals, across the baseline and 47 alternative specifications ranked by estimate; the strip below each panel marks the family of each specification (unit of analysis, region fixed effects, sample, drop-one, block drops, proxy swaps, alternative outcomes). Hollow markers are proxy swaps that replace the tracked covariate itself (the all-employee wage for the wage index; the rural indicator, a 0/1 dummy, for population density) and are excluded from the counts in the text.

Table J.1: Shapley decomposition of the post-Lasso R^2: shares and bootstrap intervals

Covariate	Block	Share of R2 (%)	95% interval (share)	R2 units	95% interval (R2 units)
Plumber wage, TTWA synthetic (2019, GBP)	Supply	38.9	[22.7, 77.7]	0.200	[0.033, 0.303]
Mean temperature (long-term avg.)	Demand	21.9	[0.6, 32.1]	0.112	[0.001, 0.197]
Self-employment share, construction (MSOA)	Supply	14.4	[2.9, 34.0]	0.074	[0.005, 0.112]
Population density (persons/ha)	Demand	14.1	[0.3, 18.1]	0.072	[0.000, 0.095]
Distance to nearest HTG training centre, km	Supply	10.7	[1.0, 49.1]	0.055	[0.002, 0.131]
Demand block (subtotal)	Demand	36.0		0.185	
Supply block (subtotal)	Supply	64.0		0.328	
Total (model R2)		100.0		0.513	

Shapley (LMG) decomposition of the R2 of the post-Lasso OLS of A_m on the 5 Lasso-selected covariates, England estimation sample (N = 31,441 LSOAs in 155 TTWAs), selection held fixed. Shares sum to 100% of the model R2 (0.513). Intervals: 2.5th-97.5th percentiles over 2,000 cluster-bootstrap draws of TTWAs (share intervals normalised within draw). In-sample association; the TTWA-level outcome is broadcast to LSOAs, so shares are LSOA-weighted.

Shapley decomposition. Figure 5 and Table J.1 partition the post-Lasso R^2 (0.513) across the five selected covariates using a Shapley (LMG) decomposition (Israeli, 2007; Shapley, 1953; Shorrocks, 2013). Each covariate's contribution is its marginal addition to R^2 averaged across all $2^5 = 32$ subset regressions weighted by $|S|!\,(k-|S|-1)!/k!$. We construct 95% confidence intervals via 2,000 cluster-bootstrap draws at the TTWA level (resampling the 155 TTWAs with replacement, stacking their constituent LSOAs, and normalising shares by each draw's total R^2).

Covariates and training-centre distance. Table J.2 reports summary statistics for the competition outcomes and the 18 candidate covariates in raw units prior to standardisation, and Table J.3 documents the data sources and definitions. To construct distance to the nearest heat pump training centre, we use the Department for Energy Security and Net Zero's list of approved Heat Training Grant providers published on 8 November 2023 (the earliest archived release), geocode each provider's postcode via the ONS Postcode Directory, and compute the great-circle distance in kilometres from each LSOA's postcode-mean centroid to the nearest provider. Because the Heat

Training Grant operates only in England, the determinants analysis is restricted to English LSOAs.

Table J.2: Covariates Local Competition Determinants Analysis: Descriptive Statistics

Metric	Mean	SD	Min	Max
Competition (outcome A_m and raw measures)				
Standardized inverse HHI (A_m)	0.983	1.68	-1.49	4.21
Inverse HHI (effective installers)	23.9	14.6	2.28	52.1
HHI ($\times$ 10,000)	680	635	192	4,390
Demand				
Share gas central heating (2011)	0.797	0.181	0.0132	0.984
Share house (detached + semi, 2011)	0.553	0.279	0	0.998
Mean EPC score, houses (2015-2022)	60.6	4.74	10	86
Share owner-occupied (2011)	0.649	0.204	0.00954	0.979
Deprivation index (IMD)	21.4	15.4	0.5	92.6
Solar PV per household (MCS, to 2022)	0.191	0.23	0	5.01
Mean temperature (long-term avg.)	10.7	0.697	6.63	12.3
Solar capacity factor	0.114	0.00567	0.0927	0.132
Log households (2011)	6.49	0.178	5.97	7.16
Population density (persons/ha)	42.3	41.6	0.0262	685
Green vote share (notional 2019)	0.0298	0.0315	0	0.57
Green candidate stood (notional 2019)	0.948	0.222	0	1
Supply				
Plumber rate (SOC 5314, per 1,000 residents, MSOA)	2.79	1.27	0	8.49
UKBC local units per 10k pop. (SIC 43220)	7.17	1.75	3.54	12.6
Self-employment share, construction (MSOA)	0.418	0.0856	0.126	0.735
Plumber wage, TTWA synthetic (2019, GBP)	14.7	1.51	10.5	19.8
Distance to nearest HTG training centre, km	20.3	17.2	0.052	122
Mean commute distance (2011)	14.9	4.41	3.71	47

England estimation sample of the determinants regression: N = 31,441 LSOAs in 155 TTWAs. Raw units before standardisation on this sample. For the continuous covariates the SD column is the unit of the regression coefficients (one SD of the covariate); the Green-candidate indicator enters the regression as a 0/1 dummy, so its mean is the share of LSOAs with a Green candidate. A_m is the paper's index, standardised across the 218 GB TTWAs, so its unit is one GB-TTWA SD of the inverse HHI (8.74 effective installers), not the sample SD shown here.

Table J.3: Competition Analysis Covariate List

Concept	Variable	Definition	Source	Geography	Year
Demand					
Gas access	Share gas central heating (2011)	Share of households whose central heating is gas	Census 2011	LSOA	2011
Dwelling suitability	Share house (detached + semi, 2011)	Share of dwellings that are detached or semi-detached houses (sum of the two Census shares; base = terraced, flats, other)	Census 2011	LSOA	2011
Dwelling suitability	Mean EPC score, houses (2015-2022)	Mean of annual LSOA-mean EPC energy-efficiency scores (SAP points) for houses, 2015-2022	MHCLG open EPC register, 2015-2022 mean	LSOA	2015-2022
Decision power	Share owner-occupied (2011)	Share of households that own their home (outright or with a mortgage)	Census 2011	LSOA	2011
Ability to pay	Deprivation index (IMD)	Index of Multiple Deprivation, UK-harmonised via the income and employment domains (higher = more deprived)	UK-harmonised IMD (Abel, Barclay & Payne 2016)	LSOA	2015 (E), 2014 (W)

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Concept	Variable	Definition	Source	Geography	Year
Green / savvy improver	Solar PV per household (MCS, to 2022)	Cumulative MCS-registered solar-PV installations to end-2022, per 2011 household	MCS register, cumulative to 2022, per 2011 household	LSOA	to 2022
Climate	Mean temperature (long-term avg.)	Long-term average air temperature (degrees C)	Met Office HadUK-Grid v1.3.1 (CEDA), 1 km annual mean tas, long-term average	LSOA	LTA
Climate	Solar capacity factor	Long-term average solar-PV capacity factor (share of nameplate)	Global Solar Atlas v2 (World Bank/Solargis), long-term average PVOUT	LSOA	LTA
Market size	Log households (2011)	Log of the number of households	Census 2011	LSOA	2011
Market size	Population density (persons/ha)	Usual residents per hectare	Census 2011 QS102EW (Nomis)	LSOA	2011
Green preferences	Green vote share (notional 2019)	Green Party share of the notional 2019 general-election vote in the LSOA's constituency	BES 2024 (notional 2019 result, 2024 boundaries)	Constituency	2019

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Concept	Variable	Definition	Source	Geography	Year
Green preferences	Green candidate stood (notional 2019)	0/1: a Green candidate stood in the constituency (controls the seats with no Green candidate; enters as a level shift, not per SD)	BES 2024 (notional 2019 result, 2024 boundaries)	Constituency	2019
Supply					
Trades base	Plumber rate (SOC 5314, per 1,000 residents, MSOA)	Residents employed as plumbers and heating/ventilating engineers (SOC 5314) per 1,000 residents	Census 2011 CT0347 (Nomis NM_970_1), SOC 5314	MSOA	2011
Firm counts	UKBC local units per 10k pop. (SIC 43220)	Local units (business sites, not enterprises) in SIC 43220 plumbing, heat and air-conditioning installation, per 10,000 residents (mid-2011)	UK Business Counts 2022 (Nomis NM_141_1), SIC 43220 local units	TTWA	2022
Self-employment	Self-employment share, construction (MSOA)	Share of employed construction-industry residents who are self-employed	Census 2011 DC2604EW (Nomis NM_696_1)	MSOA	2011

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Concept	Variable	Definition	Source	Geography	Year
Labour cost	Plumber wage, TTWA synthetic (2019, GBP)	Synthetic plumber hourly wage: TTWA all-employee median gross hourly pay (Table 11) x population-weighted blend of the regional SOC 5314 / all-occupations median ratios (Table 15)	ASHE 2019 Tables 11 & 15 (synthetic)	TTWA	2019
Training access	Distance to nearest HTG training centre, km	Great-circle distance from the LSOA (postcode-mean) centroid to the nearest Heat Training Grant provider (England-only scheme)	DESNZ Heat Training Grant provider list (Nov 2023)	LSOA	2023
Market reach	Mean commute distance (2011)	Mean distance travelled to work by employed residents, km	Census 2011 (mean distance travelled to work)	LSOA	2011

Curated covariate set: one or two proxies per concept, 18 covariates (12 demand, 6 supply), listed in the order used in every table and in the coefficient plot. Vintages range from the 2011 Census to the November 2023 training-provider list (see Year). Continuous covariates are standardised on the England estimation sample (coefficients per 1 SD); the Green-candidate dummy enters as a 0/1 level shift. MSOA-, TTWA- and constituency-level covariates are broadcast to their LSOAs.

K A simple model of subsidy-induced entry

This appendix extends the linear Cournot example of Section 2, equation (5), to endogenise the number of active installers via free entry. Retaining the notation of Section 2 while dropping the market subscript m, let inverse demand for installations as a function of the gross invoice price p and per-unit grant s be

$$p = a + s - b\,Q. \tag{25}$$

Potential installers $k \in \{1, 2, \dots\}$ compete in quantities, ordered from lowest to highest cost: installer k has constant marginal cost $c_k = c + (k-1)\zeta$ and faces a sunk local-market entry cost $\Phi_k = (k-1)\Phi$, where $\zeta \geq 0$ and $\Phi > 0$. Installer 1 represents the local incumbent ($\Phi_1 = 0, c_1 = c$), while higher-indexed entrants represent firms located progressively further away or facing higher training and setup barriers.

K.1 Cournot equilibrium and free entry

Let $M \equiv a + s - c$ denote the baseline market size parameter and $M_N \equiv M - \zeta(N+2)(N-1)/2$ denote the N-th installer's effective market margin. With N active installers, summing the Cournot first-order conditions yields the equilibrium gross price, aggregate quantity, and variable profit of the marginal (N-th) installer:

$$p = c + \frac{M + \zeta N(N-1)/2}{N+1}, \qquad Q = \frac{N\,[\,M - \zeta(N-1)/2\,]}{b\,(N+1)}, \qquad \Pi_N = \frac{M_N^2}{b\,(N+1)^2}, \tag{26}$$

which reduce to equation (5) when $\zeta = 0$.

Installer N enters the local market if and only if its variable profit covers its sunk entry cost, $\Pi_N \geq \Phi_N$, which defines the entry threshold

$$M \;\geq\; \frac{\zeta(N+2)(N-1)}{2} + (N+1)\sqrt{b\,\Phi_N}. \tag{27}$$

Because the right-hand side of (27) is strictly increasing in N, the equilibrium number of active installers $N^\star(s)$ is a weakly increasing step function of the subsidy s.

K.2 Comparative statics: within-regime vs. entry-threshold effects

Within any regime where N remains constant, raising the subsidy increases the gross invoice price at rate $\partial p/\partial s = 1/(N+1) > 0$, implying incomplete pass-through to the household ($N/(N+1) < 1$). When the subsidy crosses the threshold (27) at which the N-th installer enters, however, the gross price drops discretely by

$$\Delta p = -\,\frac{\sqrt{b\,\Phi_N}}{N}. \tag{28}$$

A discrete subsidy increase can therefore reduce the pre-grant invoice price, and generate household pass-through above unity, when the market expansion is large enough to induce local entry and the threshold price drop (28) outweighs the within-regime price increases on either side of the threshold. Notice that the marginal-cost gradient ζ shifts the entry threshold (27) upward without altering the size of the threshold jump (28). Evaluated at the entry thresholds, the upper envelope of gross prices is $p = c + \sqrt{b\,\Phi_N} + (N-1)\zeta$, so higher training or skill-acquisition barriers raise the grant required to trigger entry.

K.3 Illustrative calibration and caveats

Figure K.1 illustrates the equilibrium path as a function of the per-installation subsidy s for $a =$ 20,000, $c = 8{,}000$, $b = 40$, $\Phi = 253{,}000$, and $\zeta = 0$ (in pounds), alongside a counterfactual in which the market is restricted to a single monopolist ($N = 1$). Under these illustrative parameters, a third installer enters at $s \approx$ £5,996, between the pre- and post-reform BUS grant levels of £5,000 and £7,500. Over the £5,000 to £7,500 grant increase, the gross price falls by approximately £792: within-regime increases totalling £708 are more than offset by the £1,500 drop at the entry threshold. Consequently, the household's out-of-pocket price falls by £3,292 (pass-through of 1.32), installations rise by 29%, and consumer surplus rises by 67%. By contrast, in the single-firm counterfactual where entry is blocked, the same £2,500 grant increase raises the gross price by £1,250 and yields a pass-through rate of 0.50.

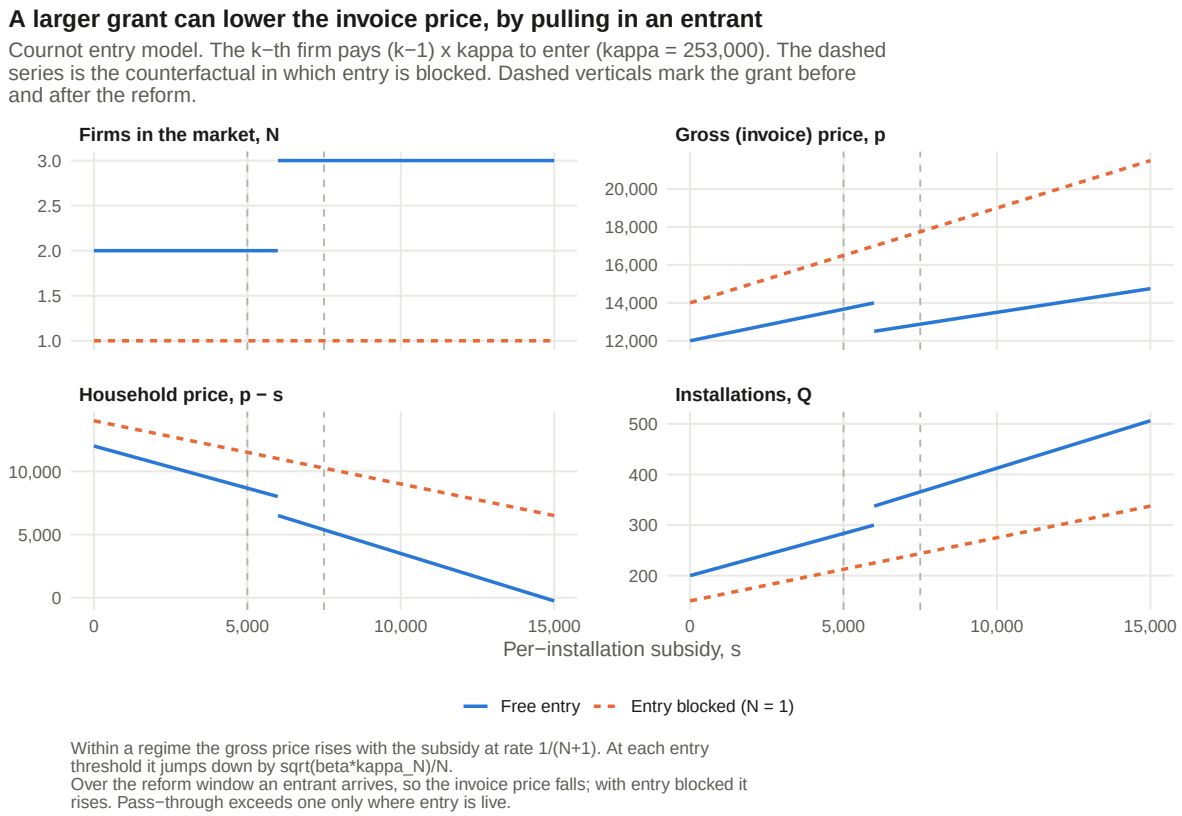

Figure K.1: Subsidy-induced entry and the gross price

Notes. Equilibrium of the model in equations (25)–(27) as a function of the per-installation grant. Solid lines allow free entry; dashed lines hold the market at a single installer. Dashed vertical lines mark the pre- and post-reform grant values of £5,000 and £7,500. Calibration: $a = 20{,}000$, $c = 8{,}000$, $b = 40$, $\Phi = 253{,}000$, $\zeta = 0$. Within an entry regime the gross price rises with the grant at rate $1/(N+1)$; at each entry threshold it falls discretely by $\sqrt{b\,\Phi_N}/N$. The figure is produced by the replication code accompanying the interactive version of the model.

This stylized benchmark abstracts from within-firm capacity constraints, waiting times, and product differentiation. Because the discrete price jump $\sqrt{b\,\Phi_N}/N$ decreases in N for a single market

crossing a single threshold, generating a larger average price drop in thicker markets requires either a distribution of entry thresholds across local areas, such that a given subsidy increase pushes more installers across the entry margin in thicker markets with lower entry barriers Φ and ζ, or the compositional and reallocation channels documented in Section 5.3. Finally, while consumer surplus increases unambiguously at an entry threshold, domestic total surplus net of the environmental externality need not rise because sunk entry costs Φ_N duplicate fixed resources and entrants steal business from incumbents (Mankiw & Whinston, 1986). The social return to subsidy-induced entry therefore rests on the external carbon and air-quality benefits evaluated in Section 6.