Refinancing Cross-Subsidies in the Mortgage Market

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Motivation

- Consumer finance: households struggle to make good financial decisions.
  (Campbell, 2006; Keys et al. 2016, Agarwal et al. 2016, Gomes et al., 2021)
  - Complex contracts and product design.
  - $\rightarrow$ Requires attention and action.

- Considerable heterogeneity in attention/inaction, prices paid.
  - Less attentive households get worse deals.
  - Cross-subsidize more attentive consumers who are "cut in on the deal."
    (Miles, 2004, Gabaix and Laibson, 2006, Armstrong and Vickers, 2012.)

- Attentiveness/financial sophistication is correlated with wealth and income.
  (Campbell et al. 2019, Greenwald et al. 2021.)
  - Design of financial products and contracts can materially amplify inequality.

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- Attentiveness/financial sophistication is correlated with wealth and income.
  (Campbell et al. 2019, Greenwald et al. 2021.)
  - Design of financial products and contracts can materially amplify inequality.
  - How large are the effects? What are the mechanisms?

A Simple Illustration of Cross-Subsidization

- Consumers:
  - Endowed with base good at price p_l, defaulted into add-on good at price p_h.
  - Can substitute to base good at price p_l by paying k (same utility).
  - Unit demand, aggregate normalized to 1.
- Firm:
  - Sells base good (p_l) and add-on good ($p_h > p_l$), both prices positive.
- Costs and choice:
  - Assume household costs distributed uniformly $k \sim U(0, \bar{k})$.
    - Define threshold $k^* \equiv p_h - p_l$ (benefit of action)
    - Households with cost of action $k > k^*$ pay add-on price p_h.
    - Households with $k \leq k^*$ pay base price p_l in addition to cost.

Cross-Subsidization From High to Low-Cost Consumers

- Expected firm revenues:

$$\frac{k^*}{\bar{k}} p_l + (1 - \frac{k^*}{\bar{k}}) p_h \tag{1}$$

- Consider single price p^* (no add-on pricing) under expected revenue equivalence:

$$\underbrace{p^*}_{\text{Revenues under single price}} = \underbrace{\frac{k^*}{\bar{k}} p_l + (1 - \frac{k^*}{\bar{k}}) p_h}_{\text{Revenues exp. under dual price}} \tag{2}$$

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- Which implies:

$$p_l < p^* < p_h \tag{3}$$

- Cross-subsidy (dual- vs. single-price) is transfer from high k to low k households:
  - When moving to single-price world, low k consumers lose $\frac{k^*}{\bar{k}} p^* - \frac{k^*}{\bar{k}} p_l$, equal to...
  - ...high k consumers' gain: $(1 - \frac{k^*}{\bar{k}}) p_h - (1 - \frac{k^*}{\bar{k}}) p^*$

This Paper

- Studies mortgage refinancing in the UK.
  - Mortgages: Largest household liability; cross-household differences in refinancing efficiency (Andersen et al, 2020; Keys et al., 2018).
  - UK: initial discounted rates fixed for 2-5 years, automatically reset to high variable rate, unless refinanced into another discounted rate.

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- Data: universe of UK outstanding mortgage stock.
- Model: partial equilibrium model of UK mortgage market.
  - Heterogeneity in refinancing costs and valuations for housing.
  - Structurally estimate model parameters to match moments in the data.

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- Data: universe of UK outstanding mortgage stock.
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  - Heterogeneity in refinancing costs and valuations for housing.
  - Structurally estimate model parameters to match moments in the data.
- Structural approach means we can assess and quantify:
  - Size of cross-subsidy by comparing to a counterfactual single-rate market design.
  - Distribution of cross-subsidies: across income groups and regions of the UK.
  - Differential margins of adjustment.

Institutional Framework and Data

The UK Mortgage Market

- Mortgages pay discounted ("teaser") rate for initial fixation period (2-5 years), which reverts to high variable reset rate unless refinanced after fixation period.
  - Similar to credit cards, cellphone/electricity plans (Armstrong and Vickers, 2012).
  - Pricing based on product characteristics: rate type, fixation period, LTV.
    - Prices homogenous across borrowers conditional on product (different from US).

- Limited frictions to remortgaging: 2019 FCA Mortgage Market Study notes that remortgaging is easy, and most often with initial lender.
  - Filter ∼40K of 2M on reset rate that cannot refinance ("mortgage prisoners").
  - Filter potentially refinancing-ineligible borrowers (high LTV, payment shortfalls etc).

Data Filtering Table

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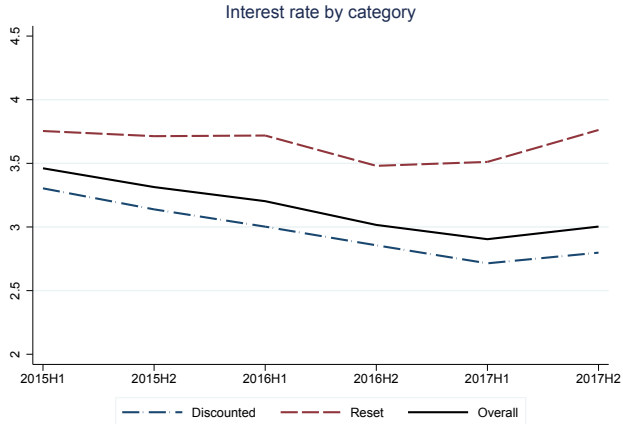
  Data Filtering Table

- Simplified optimal refinancing problem Option Value Simulation
  - Significant refinancing incentives at the end of fixed period (Cloyne et al., 2019).
  - Mortgages are portable (reduced role of unobserved moving propensities).
  - High prepayment penalties deter early refinancing.

Data

- Data sourced from the Financial Conduct Authority (PSD007).
- Tracks stock of all outstanding loans issued by regulated financial institutions in the UK, at semi-annual frequency.
- Data from June 2015–December 2017, we mainly utilize stock at June 2015 (2015H1) in this draft.
  - Eliminate tracker mortgages, focus on discounted and reset rate mortgages.
  - 3.59M mortgages, £470B aggregate debt in 2015H1
- Granular mortgage details, tracked over time, limited borrower characteristics (age, income, location).
- Used in other studies of UK mortgage markets: among others, Cloyne et al., 2019; Benetton, 2021; Robles-Garcia, 2019; Benetton et al. 2021; Liu, 2022.

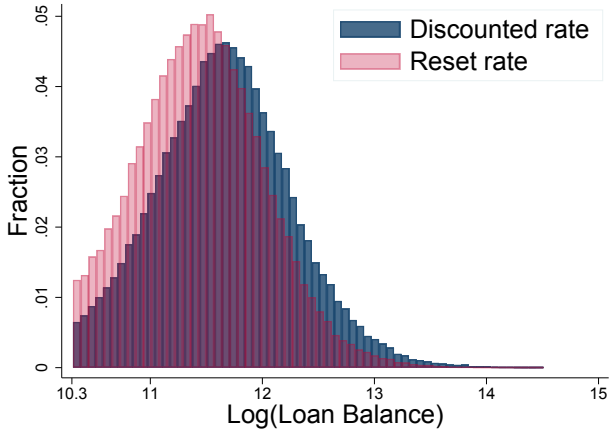
Average Interest Rates on Discounted and Reset Rates



- Average interest rate differential between reset and discounted rate in 2015H1: 54.5bp

→ Benefit of refinancing (per unit of loan)

Distribution of Loan Balances on Discounted and Reset Rates



- 69.8% of mortgage (by loan balance) on discounted rate, 30.2% on reset rate. More Detail
- Average loan balance: £140,647 on discounted vs. £112,692 on reset rate.

→ Cross-sectional variation in initial loan balance, time-series variation in remaining years.

An Outline of the Model

Motivating the Model Framework

To model cross-subsidies accurately, a desirable model will:

- Capture different loan sizes.
  - Model the intensive margin decision using distribution of value for housing.
- Capture heterogeneity in refinancing cost.
  - Include both a persistent component of k as well as time-varying inaction (random shock to "refinancing attention").
- Map to the stock of mortgages and not just the flow.
  - Direct measure of full lender portfolio; captures behaviour across the maturity spectrum; estimated parameters not influenced by changes over short periods.
- Be easy to aggregate to understand how cross-subsidies flow (including across income and regional groups).

Model: Assumptions

- Households:
  1. Enjoy per-period housing value v_i
  2. Pay a fixed cost $k_{i,t} = k_i \varepsilon_{i,t}$ at the point of refinancing:
     - k_i is persistent cost for household i.
     - $\varepsilon_{i,t}$ household-specific multiplicative shock. Non-negative, iid with $f(\varepsilon_{i,t})$.
  - Valuations, costs described by joint cdf $G(v_i, k_i)$, pdf $g(v_i, k_i)$.

- Mortgages:
  - Last for T periods. Discounted rate r_d for the initial T_d periods.
  - Reset rate $R > r_d$ after T_d periods, if the household does not refinance.

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- Choices:
  - At $t = 0$, decide to buy a property or rent (extensive margin).
  - At $t = 0$, if they buy, households choose loan size $l_{i,0}$ to finance a property priced at h_i, where $h_i = \omega l_{i,0}$ and LTV $= \frac{1}{\omega}$ (intensive margin).
  - Every T_d periods, households decide to refinance or not by paying $k_{i,t}$.

Model: Optimal Refinancing

- Intuition:
  - Households refinance when $k_{i,t}$ is below a threshold that depends on loan balance.
  - Across households: larger loans increase refinancing likelihood.
  - Over time: refinancing incentives decline as loan amortizes.
  - Some households (almost) always refinance due to low persistent k_i.

- Solve for optimal refinancing path by backward induction:
  - In period T, refinance if $k_{i,T}$ below cutoff point $k_i^*(T)$

$$\begin{aligned} k_i^*(T) &= m(l_{i,T-1}, R, 1) - m(l_{i,T-1}, r_d, 1) \\ &= \underbrace{l_{i,T-1}(R - r_d)}_{\text{Benefit of refinancing at time } T} . \end{aligned}$$

Model: Optimal Refinancing (cont'd)

- Value function at time T:

$$V_T(k_i, l_{i,T-1}) = \mathbb{E}_{\varepsilon_{i,T}}\left[\max\left\{-m(l_{i,T-1}, R, 1), -m(l_{i,T-1}, r_d, 1) - k_i \cdot \varepsilon_{i,T}\right\}\right]$$

$$= \int_0^{k_i^*(T)/k_i} \underbrace{\left(-m(l_{i,T-1}, r_d, 1) - k_i \cdot \varepsilon_{i,T}\right)}_{\text{cost on discounted}} dF(\varepsilon_{i,T}) +$$

$$\int_{k_i^*(T)/k_i}^{+\infty} \underbrace{\left(-m(l_{i,T-1}, R, 1)\right)}_{\text{cost on reset}} dF(\varepsilon_{i,T}).$$

Model: Optimal Refinancing (cont'd)

- Value function at time T:

$$\begin{aligned} V_T(k_i, l_{i,T-1}) =& \mathbb{E}_{\varepsilon_{i,T}}\left[\max\left\{-m(l_{i,T-1}, R, 1), -m(l_{i,T-1}, r_d, 1) - k_i \cdot \varepsilon_{i,T}\right\}\right] \\ =& \int_0^{k_i^*(T)/k_i} \underbrace{\left(-m(l_{i,T-1}, r_d, 1) - k_i \cdot \varepsilon_{i,T}\right)}_{\text{cost on discounted}} dF(\varepsilon_{i,T}) + \\ & \int_{k_i^*(T)/k_i}^{+\infty} \underbrace{\left(-m(l_{i,T-1}, R, 1)\right)}_{\text{cost on reset}} dF(\varepsilon_{i,T}). \end{aligned}$$

- Similarly, define $V_t(k_i, l_{i,t-1})$ in generic period, with refinancing threshold $k_i^*(t)$.
- Optimal refinancing policy:

$$r(l_{i,t-1}, k_{i,t}) = \begin{cases} r_d & \text{if } k_{i,t} \leq k_i^*(t) \\ R & \text{otherwise.} \end{cases}$$

Model: Optimal Loan Size

- Households choose initial loan size that maximizes value function at origination:

$$W_0(v_i, k_i) = \max_{l_{i,0}} \sum_{t=0}^{+\infty} \beta^t v_i (\omega_i l_{i,0})^\alpha - k_i + \beta V_1(k_i, l_{i,0}),$$

- Optimal loan size $l^*_{i,0}(v_i, k_i)$ depends directly on v_i, and indirectly on persistent component k_i of refinancing cost, through optimal refinancing policy $r(l_{i,t-1}, k_{i,t})$.
  - Households with a higher k_i scale back initial loan, anticipating more reset rate payments (matters for counterfactuals).

- Extensive margin condition (EMC):

$$W_0(v^*_i, k_i) \geq \frac{\bar{u}}{1-\beta},$$

where $v^*_i(k_i)$ is the housing valuation at which household is indifferent between getting a mortgage or renting; $\bar{u}$ is a per-period utility of the outside rental option.

Model: Aggregation and the Stock of Mortgages

- Define three groups (i) of mortgages; derive aggregate number $N_i(\cdot)$ and aggregate balance $Q_i(\cdot)$ of mortgages in each group *in steady state*.
- Group 0: households with initial loan size $l_0(v, k)$ on their initial discounted rate.
  - Number $N_0(r)$ and quantity $Q_0(r)$ of these mortgages just adds all initial home buyers (all who satisfy EMC).
- Group 1: Mortgages of households who refinanced into the discounted rate.
  - Number $N_1(r)$ and quantity $Q_1(r)$ of these mortgages adds all refinancers (those with k below k^* in each cohort observed in steady state, satisfying EMC).
- Group 2: Mortgages of households who did not refinance, and pay the reset rate.
  - Number $N_2(R)$ and quantity $Q_2(R)$ of these mortgages just adds all reset rate payers (those with k above k^* in each cohort observed in steady state, satisfying EMC).

Structural Estimation

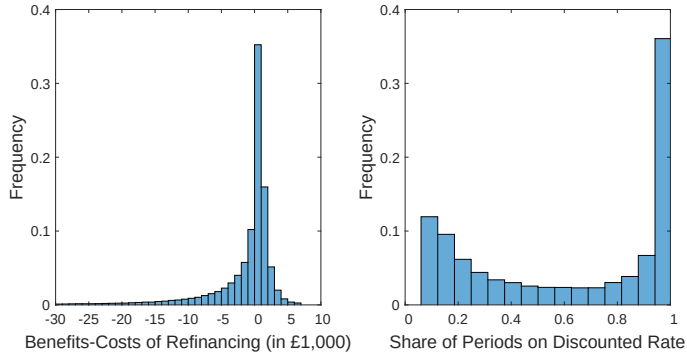
Outline of Structural Estimation

- The model allows for a convenient aggregation of outstanding mortgages $\rightarrow$ distribution of mortgages on the discounted and reset rate. Aggregation Details
- We estimate the model by matching moments from distributions of mortgages in mortgage stock data.
  - Assumption: market is in steady state. Transition Probabilities
- We estimate the distributions of housing valuations and refinancing costs, the variance of temporary component of refinancing cost shocks, utility parameters. Parameter Estimates
- Three versions:
  1. UK-wide;
  2. 12 income groups;
  3. 12 regions and devolved administrations.

Model Fit: UK-wide

	Data	Model
Mean Loan Balance, Discounted Rate	140,647	143,697
Standard Deviation Loan Balance, Discounted Rate	105,062	106,551
Mean Loan Balance, Reset Rate	112,692	113,741
Standard Deviation Loan Balance, Reset Rate	79,684	76,546
Mean Remaining Years, Discounted Rate	20.57	18.63
Standard Deviation Remaining Years, Discounted Rate	7.73	7.91
Mean Remaining Years, Reset Rate	16.84	15.56
Standard Deviation Remaining Years, Reset Rate	6.95	7.40
Share of Mortgages on Discounted Rate, 0-5 Percentile	52.72	52.82
Share of Mortgages on Discounted Rate, 5-25 Percentile	56.36	58.03
Share of Mortgages on Discounted Rate, 25-50 Percentile	61.48	60.12
Share of Mortgages on Discounted Rate, 50-75 Percentile	67.76	63.73
Share of Mortgages on Discounted Rate, 75-95 Percentile	73.77	72.10
Share of Mortgages on Discounted Rate, 95-100 Percentile	81.19	83.66
Transition from Reset Rate to Discounted Rate	16.52	16.42
Share of Owners	63.13	64.50

Net Benefits of Refinancing



- Large heterogeneity in net benefits in the cross section, with costs more heterogenous than gross benefits.
- Large heterogeneity of refinancing behavior in the time series (refinancing paths).

Cross-Subsidies and How They are Distributed

Model: Computing Cross-Subsidies

- Evaluate counterfactual in which all households pay single constant rate r_c
  - In the following, focus on value-weighted average r_c Single Rate Alternatives
- Optimal loan size $l^{**}_{i,0}(v_i, k_i)$ in this case maximizes the value function at origination evaluated at $k_i = 0$.
- We can compute the aggregate number and balance of mortgages in this scenario.
- We also apply the model to groups $j = 1, \ldots, J$ of households by maximizing the value function at origination evaluated at $k_i = 0$, but using group-specific parameters.
  - We can thus calculate group-specific (e.g., income, geographic regions) cross-subsidies. Aggregation Details

Market Outcomes In Single-Rate Counterfactual

	UK-wide	Income Groups	Regions
	(1)	(2)	(3)
Constant Interest Rate=683 bps			
Number of Mortgages	1.06	1.10	1.07
Mean Initial Loan Amount	0.98	0.96	0.97
Standard Deviation Initial Loan Amount	0.96	0.92	0.95
Mean Loan Balance	0.98	0.97	0.97
Standard Deviation Loan Balance	0.97	0.93	0.96

Notes: Counterfactual quantities in rows shown as ratios relative to estimated market with dual interest rates.

Cross-Subsidies Across Income and Regional Groups

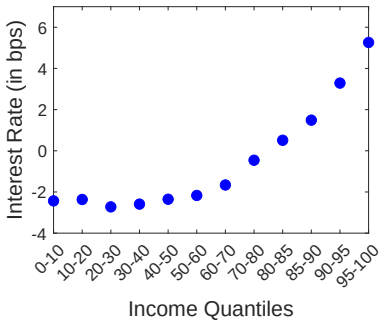
- Next, we re-estimate the model for a set of subgroups of the data:
  - 12 income groups (10 income deciles, top decile further subdivided into two groups).
  - 12 UK regions and devolved administrations.

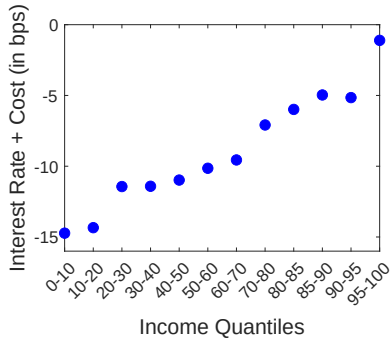
- Using group-specific parameters, calculate:
  - Average interest rate change (under single- vs dual-rate) for each group.
  - Average loan balance change.
  - Average annual payment change.

- There is considerable *within-group* variation in the data, but in this exercise, focus on *across-group* distribution of cross-subsidies.

Differences in Outcomes, Dual-Rate to Single-Rate, Income Groups (I)

Progressive redistribution in average interest rates and changes to total mortgage cost.



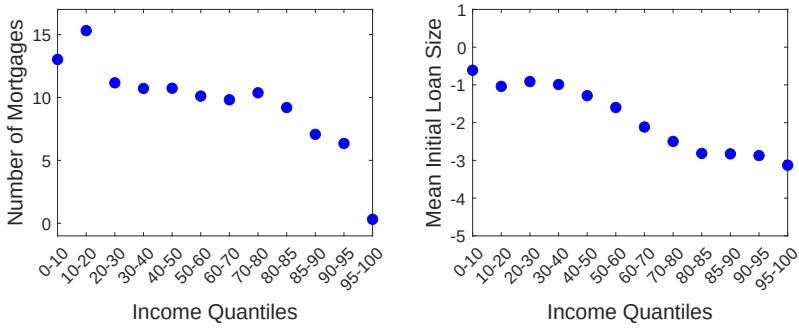


- Income groups from 80th percentile pay higher rates in counterfactual.
  - Effect driven by higher-income households having larger loan balances.

$\rightarrow$ Significant reduction in total mortgage cost: $\approx$ £1,000-2,000, or 1-2%

Differences in Outcomes, Dual-Rate to Single-Rate, Income Groups (II)

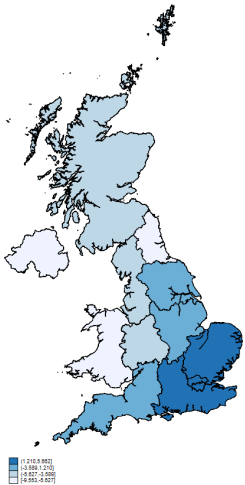
Significant adjustments to entry and mortgage debt in response to single-rate regime.



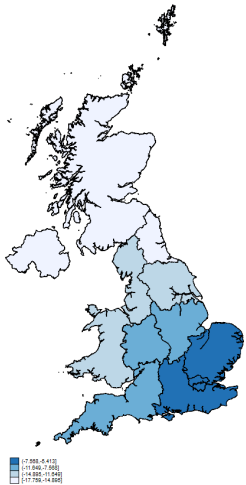
- Low-income households: increase in number of mortgages (low ν).
- High-income households decrease in loan balances (high ν). Descriptive Statistics, Income

Differences in Outcomes, Dual-Rate to Single-Rate, Regional (I)

Progressive North-South redistribution. Descriptive Statistics, Regions



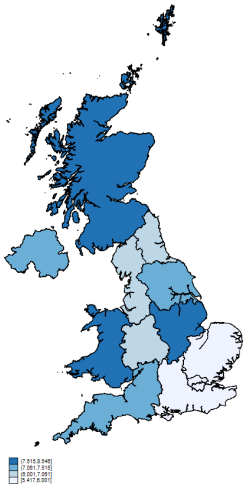
(a) Interest Rate



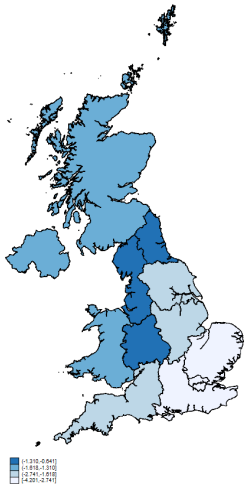
(b) Mortgage Cost

Differences in Outcomes, Dual-Rate to Single-Rate, Regional (II)

Extensive and intensive margin adjustments across regions.



(c) Number of Mortgages



(d) Mean Initial Loan Size

Cross-Subsidy Mechanisms

- Redistributive effects depend on both refinancing cost k & housing valuation v.
  - Status quo penalizes high-k households, who mostly pay high reset rate R.
  - Status quo also penalizes low-v households—typically lower income— since smaller v implies smaller l_0, lowering the refinancing benefit k^*, leading to less time spent on the discounted rate (r_d).

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- Margins of adjustment
  - Large effects on extensive margin for low-income (typically low v) households who enter the single-rate market but are deterred from dual-rate market.
  - Large effects on intensive margin for high-income (typically high v) households who take smaller loans in single-rate market. Elasticities

Conclusion

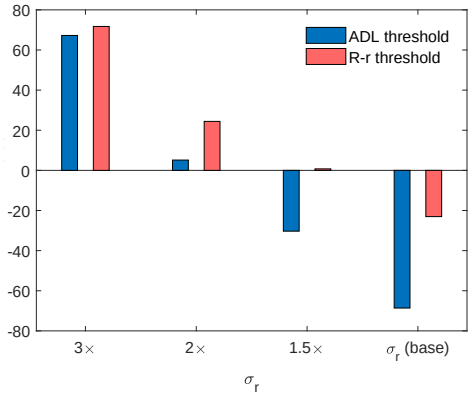
- Structurally estimate refinancing cross-subsidies in the UK mortgage market.
  - Match broad features of the data, with realistic parameters that highlight significant cross-household variation in refinancing costs and incentives.

- Effect of removing cross-subsidy on composition of mortgage stock:
  - Greater take-up for poorer groups/regions.
  - "Democratization" of mortgage take-up in single-rate world.

- **More broadly: cross-subsidies & inequality in consumer finance**
  - Richer households benefit due to larger stakes and greater propensity to take action.
  - Complex product design (costly action) disproportionately affects the poor.

Appendix

Simulation of Option Value on the Revert Rate (Varying σ_r)



Notes: This figure displays the simulated net present value of the option to refinance when staying on the reset rate, under different calibrations of interest rate volatility and comparing the ADL optimal refinancing threshold with a threshold that corresponds to the difference between the reset and discounted rate.

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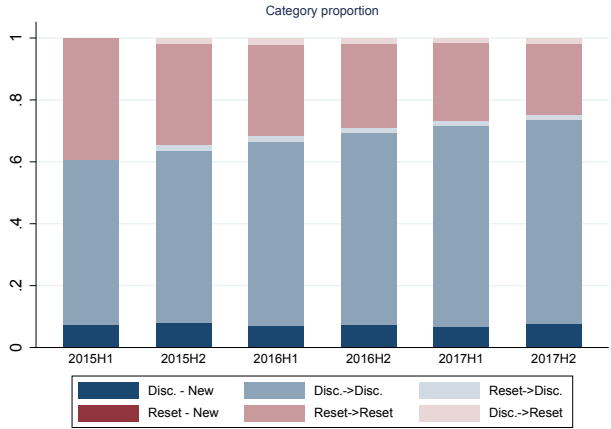
Data Filters, Ineligible to Refinance

	2015H1	2015H2	2016H1	2016H2	2017H1	2017H2
All	100%	100%	100%	100%	100%	100%
(1) LTV>=95	2.3%	1.9%	2.2%	2.4%	2.4%	3.6%
(2) Balance<=30000	6.5%	6.5%	6.7%	6.7%	6.9%	6.9%
(3) Non-performing	5.5%	5.0%	3.9%	3.9%	3.8%	3.6%
All excl. (1),(2),(3)	86.4%	87.2%	87.7%	87.4%	87.4%	86.3%

Go back

Fraction of Mortgages on Discounted and Reset Rates



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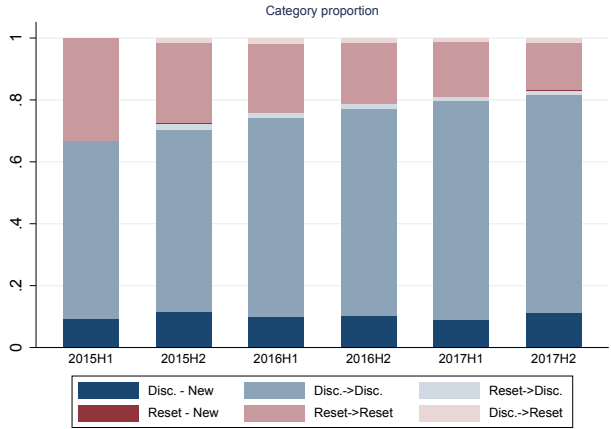
Fraction of Mortgage Stock on Discounted and Reset Rates



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Value Functions

- Value function at time T with refinancing threshold $k_i^*(T)$:

$$\begin{aligned} V_T(k_i, l_{i,T-1}) =& \mathbb{E}_{\varepsilon_{i,T}}\Big[\max\big\{-m(l_{i,T-1}, R, 1), -m(l_{i,T-1}, r_d, 1) - k_i \cdot \varepsilon_{i,T}\big\}\Big] \\ =& \mathbb{P}\big(k_i \cdot \varepsilon_{i,T} \leq k_i^*(T)\big) \cdot \big(-k_i \cdot \mathbb{E}\big[\varepsilon_{i,t} | k_i \cdot \varepsilon_{i,T} \leq k_i^*(T)\big] - m(l_{i,T-1}, r_d, 1)\big) \ldots \\ & \ldots + \big(1 - \mathbb{P}\big(k_i \cdot \varepsilon_{i,T} > k_i^*(T)\big)\big) \cdot \big(-m(l_{i,T-1}, R, 1)\big) \end{aligned}$$

- Similarly, define $V_t(k_i, l_{i,t-1})$ for a generic period:

$$V_t(k_i, l_{i,t-1}) = \ldots$$

$$\ldots \mathbb{E}_{\varepsilon_{i,t}}\Big[\max\big\{-m(l_{i,t-1}, R, T-t+1) + \beta \cdot V_{t+1}\big(k_i, l_{i,t-1} \cdot (1+R) - m(l_{i,t-1}, R, T-t+1)\big), \ldots$$

$$\ldots - m(l_{i,t-1}, r_d, T-t+1) - k_i \cdot \varepsilon_{i,t} + \beta \cdot V_{t+1}\big(k_i, l_{i,t-1} \cdot (1+r_d) - m(l_{i,t-1}, r_d, T-t+1)\big)\big\}\Big]$$

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Model: Aggregation and the Stock of Mortgages

- Define three groups (g) of mortgages, and derive the aggregate number $N_g(\cdot)$ and aggregate balance $Q_g(\cdot)$ of mortgages in each group.
  - Expressions can be directly mapped to observed stock of mortgages in each category, under the assumption that the market is in steady-state.

- First, recursively define the endogenous distribution $H_t(\cdot)$ of loan balances after t periods from their origination, given evolution of loan balances and refinancing policy:

$$H_0(z) = \iint_{\{(v_i,k_i):v_i \geq v_i^*(k_i) \cap l_{i,0}^*(v_i,k_i) \leq z\}} dG(v_i, k_i),$$

$$H_t(z) = \int_{\{l_{i,t-1}:l_{i,t}(r,l_{i,t-1}) \leq z\}} dH_{t-1}(l_{i,t-1}).$$

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Model: Aggregation and the Stock of Mortgages - Group 0

- Group 0: households with mortgage of initial size $l^*_{i,0}(v_i, k_i)$, on initial discount period.

$$N_0(r_d) = M \int_{-\infty}^{+\infty} \int_{v_i^*(k_i)}^{+\infty} dG(v_i, k_i),$$

$$Q_0(r_d) = N_0(r_d) \int_0^{+\infty} z dH_0(z) = M \int_{-\infty}^{+\infty} \int_{v_i^*(k_i)}^{+\infty} l^*_{i,0}(v_i, k_i) dG(v_i, k_i).$$

  - Intuition: recall mass M of households entering the market in each time period. The fraction of them getting (discounted-rate) mortgages equals those of them satisfying the extensive margin condition $v_i > v_i^*(k_i)$, with the outer integral integrating across the k_i distribution.

Model: Aggregation and the Stock of Mortgages - Group 1

- Group 1: Mortgages of households who refinance into paying the discounted rate.
- In each period $t \in \{1, \ldots, T-1\}$, the number $N_{1,t}(r_d)$ of mortgages is:

$$N_{1,t}(r_d) = N_0(r_d) \int_{\{l_{i,t}: r(l_{i,t}, k_{i,t}) = r_d\}} dH_t(l_{i,t})$$

  - Intuition: combines all borrowers who have a refinancing cost $k_{i,t}$ below the cutoff point $k_i^*(t+1)$, and thus have policy functions $r(l_{i,t}, k_{i,t}) = r_d$.
  - Thus, the aggregate number $N_1(r_d)$ of mortgages is $N_1(r_d) = \sum_{t=1}^{T-1} N_{1,t}(r_d)$

- The aggregate balance of this group is the sum of balances on r_d:

$$Q_{1,t}(r_d) = N_0(r_d) \int_{\{l_{i,t}: r(l_{i,t}, k_{i,t}) = r_d\}} l_{i,t} dH_t(l_{i,t}).$$

  - Thus, the aggregate balance equals $Q_1(r_d) = \sum_{t=1}^{T-1} Q_{1,t}(r_d)$.

Model: Aggregation and the Stock of Mortgages - Group 2

- Group 2: Mortgages of households who did not refinance, and pay the reset rate.
- In each period $t \in \{1, \ldots, T-1\}$, the number $N_{2,t}(R)$ of mortgages is:

$$N_{2,t}(R) = N_0(r_d) \int_{\{l_{i,t}: r(l_{i,t}, k_{i,t}) = R\}} dH_t(l_{i,t}),$$

  - Intuition: set of borrowers who have refinancing cost above cutoff point $k_i^*(t+1)$, and thus have policy functions $r(l_{i,t}, k_{i,t}) = R$.
  - Thus, the aggregate number of households who pay the reset rate equals $N_2(R) = \sum_{t=1}^{T-1} N_{2,t}(R)$.

- The aggregate balance of this group is the sum of balances on R:

$$Q_{2,t}(R) = N_0(r_d) \int_{\{l_{i,t}: r(l_{i,t}, k_{i,t}) = R\}} l_{i,t} dH_t(l_{i,t}).$$

  - Thus, the aggregate balance equals $Q_2(R) = \sum_{t=2}^{T} Q_{2,t}(R)$.

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Parameter Estimates

r	650	R	759	T	15
β	0.902	ω	1.250	η	0.500
	UK-wide		Income Groups		Regions
	(1)		(2)		(3)
μ_v	0.001		0.001		0.001
	(0.004)		(0.000)		(0.000)
σ_v	0.150		0.234		0.349
	(0.010)		(0.010)		(0.023)
μ_{k1}	4.883		4.755		4.925
	(1.066)		(0.595)		(0.424)
σ_{k1}	2.670		2.823		2.333
	(1.263)		(0.394)		(0.987)
μ_{k2}	9.164		9.088		9.188
	(0.634)		(0.184)		(0.041)
σ_{k2}	0.988		0.960		0.987
	(0.072)		(0.059)		(0.015)
σ_ϵ	1.048		0.992		1.041
	(0.180)		(0.033)		(0.056)
α	0.787		0.789		0.788
	(0.001)		(0.007)		(0.003)
$\bar{u}$	1,190		1,580		1,455
	(235)		(606)		(436)
M	379,145		27,850		31,894
			(10,407)		(15,298)

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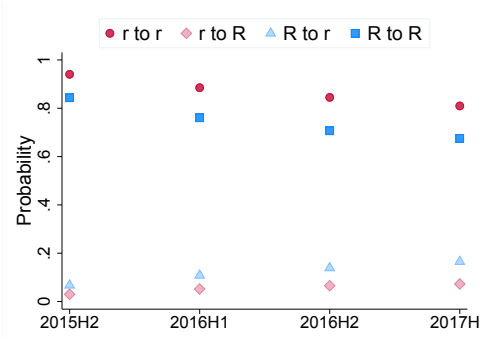
Transition Probabilities Over Time



Notes: This figure displays transition probabilities between rate types, namely from discounted to discounted, discounted to reset, reset to discounted, and discounted to discounted, over time. The transition probabilities are measured between the share of mortgages in the 2015H1 stock, and 6 to 24 months later (2015H2, 2016H1, 2016H2, 2017H1). Omitted transition probabilities are from discounted or reset rate to account closure.

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Single Interest Rate Scenarios

Several different values considered for single interest rate r_c:

1. The average discounted rate, i.e., $r_c = 650$ bps.
2. The loan-weighted average interest rate observed in the data.
3. The rate that yields the same revenue as the composite of the populations on the discounted rate and the reset rate (constant revenue assumption, requires model to compute).
4. The average reset rate, i.e., $r_c = 759$ bps.

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Descriptive Statistics, Income Groups

Quantiles	Income (£)	Homeowners (%)	Balance (£)	Discounted (%)	Spread (Reset-Discounted)
0-10	24,604	0.50	60,144	0.66	0.53
10-20	29,483	0.61	73,839	0.64	0.45
20-30	34,564	0.64	84,721	0.64	0.42
30-40	39,581	0.68	94,547	0.64	0.40
40-50	44,986	0.72	104,950	0.64	0.39
50-60	51,327	0.75	116,473	0.64	0.39
60-70	59,412	0.80	130,123	0.64	0.39
70-80	71,261	0.82	149,041	0.66	0.40
80-85	80,290	0.84	169,791	0.66	0.44
85-90	94,142	0.86	190,849	0.67	0.49
90-95	122,708	0.91	227,788	0.68	0.55
95-100	214,486	0.96	345,904	0.69	0.64

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Descriptive Statistics, UK Regions and Devolved Administrations

	Prop. (Disc.)	Disc. rate	Reset rate	Bal.
Northern Ireland	0.59	3.42	4.00	88,790
North East (England)	0.60	3.48	3.77	93,488
Scotland	0.61	3.40	3.83	102,084
West Midlands (England)	0.61	3.39	3.67	110,089
Wales	0.62	3.42	3.78	100,026
North West (England)	0.63	3.44	3.82	103,406
Yorkshire and The Humber	0.64	3.44	3.85	100,650
East Midlands (England)	0.64	3.41	3.71	106,786
South West (England)	0.67	3.31	3.61	128,260
East of England	0.69	3.24	3.72	146,888
South East (England)	0.69	3.19	3.66	165,072
London	0.69	3.00	3.83	207,592

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Mortgage Loan Elasticity With Respect to Interest Rate

- Using our estimates of α and other parameters, we can compute the loan elasticity with respect to changes in interest rates.
- In response to a 1 pp increase in the discounted rate r_d, mean loan demand changes by -1.566% (s.d. 0.722).
- In response to a 1 pp increase in the reset rate R, mean loan demand changes by -0.466% (s.d. 0.813).
  - Intuition: higher R also raises incentive to refinance.
- Broadly in line with e.g. DeFusco and Pacziorek, 2017 (1-2%).

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