For Online Publication: Online Appendix for

"Sources of Inaction in Household Finance: Evidence from the Danish Mortgage Market,"

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A. Institutional details on refinancing in Denmark.
   a. This appendix provides answers to FAQs about the process of refinancing in Denmark, obtained from the Association of Danish Mortgage Banks. These details confirm that refinancing is widely available, and largely unrestricted.
   b. Brief history of the Danish mortgage market

B. Additional tables and figures.
   a. Table B1: Determinants of Mortgage Termination. We model mortgage terminations that are driven by household-specific events, such as moves, death, or divorce, by predicting the probability of mortgage termination.
   b. Table B2: Underlying Distribution of Incentives
   c. Table B3: Differences in Household Characteristics: Refinancing and Non-Refinancing Households
   d. Table B4: Underlying Distribution of Ranked Variables
   e. Table B5: Differences in Household Characteristics: Refinancing and Non-Refinancing Households Conditional on Incentives
   f. Table B6: Counterfactual Interest Rate Saving from Refinancing
   g. Table B7: Summary Statistics of Estimated Model Parameters
   h. Table B8: Restricted Models
   i. Figure B1: Histogram of Estimated Mortgage Termination Probabilities.
   j. Figure B2: 30-year Danish Mortgage Rates, 2003-2017
   k. Figure B3: House and apartment prices, 2003-2017
   l. Figure B4: Refinancing Activity by New Mortgage Coupon Rates
   m. Figure B5: Fraction of Refinancing Households by Old Coupon Rate
   n. Figure B6: Raw Refinancing Fractions by Ranked Covariates
   o. Figure B7: Raw Refinancing Fractions by Dummy Covariates
   p. Figure B8: Refinancing Activity and Internet Search Activity
   q. Figure B9: Model Implied Asleep Probability and Internet Search Activity
   r. Figure B10: Proportionality of Coefficient Estimates
   s. Figure B11: Refinancing Activity by Asleep Probability
   t. Figure B12: Model Experiments

[1]We are grateful to the Association of Danish Mortgage Banks for providing data, and for facilitating dialogue with the Mortgage Banks. We are particularly grateful to the senior economists Bettina Sand and Kaare Christensen at the Association of Danish Mortgage Banks for providing us with valuable institutional details.

C. Replication of Table 3 and Figures 6-9, excluding all cash-out and maturity extension refinancing from the sample. Table C1 corresponds to Table 3, while Figures C1 to C4 correspond to Figures 6 to 9, respectively.

D. Replication of Table 3 and Figures 6-9, excluding households that refinance from a fixed rate mortgage (FRM) to an adjustable rate mortgage (ARM) from the sample. Table D1 corresponds to Table 3, while Figures D1 to D4 correspond to Figures 6 to 9, respectively.

E. Replication of Table 3 and Figures 6-9, with mortgages over 250K DKK and Horizon>=20. Table E1 corresponds to Table 3, while Figures E1 to E4 correspond to Figures 6 to 9, respectively.

F. ADL threshold levels under alternative assumptions.

G. Replication of Table 3 and Figures 4-9, assuming alternative interest rate volatility expectations of 0.0037. Table G1 corresponds to Table 3, while Figures G1 to G4 correspond to Figures 6 to 9, respectively.

H. Replication of Table 3 and Figures 4-9, assuming alternative discount rate of 0.025. H1 corresponds to Table 3, while Figures H1 to H4 correspond to Figures 6 to 9, respectively.

I. Replication of Table 3 and Figures 4-9, assuming a constant mortgage termination probability of 10% across households. Table I1 corresponds to Table 3, while Figures I1 to I4 correspond to Figures 6 to 9, respectively.

J. Replication of Table 3 and Figures 4-9, assuming heterogeneous responsiveness to incentives. Table J1 corresponds to Table 3, while Figures J1 to J4 correspond to Figures 6 to 9, respectively.

K. Relationship between ADL threshold and CL thresholds

L. Replication of Table 3 and Figures 4-9, using Chen and Ling (1989) thresholds. Table L1 corresponds to Table 3, while Figures L1 to L4 correspond to Figures 6 to 9, respectively.

M. Replication of Table 3 and Figures 4-9, using Chen and Ling (1989) thresholds, with mortgage over 250K DKK and Horizon>=20. Table M1 corresponds to Table 3, while Figures M1 to M4 correspond to Figures 6 to 9, respectively.

N. ADL Threshold, Interest Rate Saving and Refinancing Incentive among Prompt Refinancers

O. Simulation and Estimation of Misspecified Choice Models.

Appendix A:

The following is a list of questions and answers from our discussions with the Association of Danish Mortgage Banks regarding constraints on Danish households' ability to refinance mortgages.

The answers to several of these queries provide perspective on the controversy surrounding a recent article in The Economist newspaper, which has engendered some debate in Denmark.[2] This article suggests that the ability to refinance mortgages in Denmark is limited due to legal restrictions: "*Refinancing is an option for many, but not for the most precarious borrowers, due to legal restrictions on loans of more than 80% of a property's value.*" However, in Denmark, the article has been rebuffed by economists and market participants. For instance, the largest commercial bank Danske Bank wrote in April 2014: "*The Economist has renewed the focus on Danish households' debt in a recent article entitled 'Something rotten, Denmark's property market is built on rickety foundations'. We have looked into the arguments in the article and we conclude that it is based more on myths than realities with regard to the financial stability in Denmark."* [3]

The original correspondence with the Association of Danish Mortgage Banks is in Danish, and has been translated into English by the authors.

	Question (by the authors)	**Answer (from the Association of Danish Mortgage Banks)**
A.1	*Can households always refinance their mortgages?*	Households can always refinance if they do not increase their principal.
A.2	*Can households add the refinancing costs to their principal?*	Households have the right to refinance their mortgage, adding costs and capital loss to the new principal, as long as they stay within the same house associated with the mortgage.
A.3	*Does refinancing trigger a credit evaluation?*	No credit evaluation is done in the event of refinancing.
A.4	*Can households refinance in a situation in which the LTV has risen above 80% of the property's value, on account of declining house prices?*	Yes, households are allowed to refinance in such a situation because the value of the property is not re-assessed when households refinance. As long as the household does not increase the principal (beyond adding costs and capital loss to the new principal as described in Question A.2), the LTV will not be re-assessed and households therefore have the option to refinance.
A.5	*Do the terms of the mortgage change in case of delinquencies or default? Do households owe the market value or the face value of the mortgage to the mortgage bank?*	The terms of the loan do not change for delinquent borrowers. Mortgages can be bought back on the same terms. Thus, in case of a forced sale due to foreclosure, the borrower owes the mortgage bank the Min[Face value, Market value] plus transaction costs – foreclosure proceeds.

[2] "Danish Mortgages: Something rotten, Denmark's property market is built on rickety foundations'", The Economist. April 19, 2014.
[3] "Research Denmark: Myths and realities about large household debt", Danske Bank, April 24, 2014.

History of the Danish mortgage system

The Danish mortgage system originated in 1795 when a huge fire burned one in four houses in Copenhagen to the ground. To finance the reconstruction, lenders formed a mortgage association in 1797 and the first Danish mortgages were issued on real property on the basis of joint and several liability to enhance credit quality. Over the past 200-plus years the market has experienced no mortgage bond defaults, and only in a very few cases have payments to investors been delayed. The last example of delayed payments to mortgage bond investors occurred in the 1930s.

This track record is partly attributable to the legal framework, which was first introduced in 1850, with successive changes resulting in the current framework, which dates from 2007. The legal framework is designed to protect mortgage bond investors and confines the activities of mortgage banks to mortgage lending funded only through the issuance of mortgage bonds. Mortgage loans serving as collateral must meet restrictive eligibility criteria including LTV limits and valuation of property requirements laid down in the legislation. For instance, for private residential properties the LTV limit is 80% and mortgage banks are obliged to assess the market value of pledged properties at the time of granting the loans. The maximum loan maturity is 30 years, with an option for interest-only periods of a maximum of 10 years for private residential properties. Mortgage banks may not grant loans exceeding these limits, even to borrowers who are extremely creditworthy. However, refinancing is relatively unconstrained even for loans exceeding the LTV limit, as we discuss in the paper.

Appendix B:

Table B1: Determinants of Mortgage Termination

This table shows results from simple probit specifications which seek to uncover the determinants of mortgage termination caused by moving, or other circumstances which result in full prepayment of the mortgage. The dependent variable takes the value of 1 if a household terminates its mortgage in a given month, and 0 otherwise. Each column estimates a model with a non-linear transformation ($f(x) = \sqrt{2x^2}$) of several of the rank control variables in addition to their levels x. As before, we estimate these specifications using all households in Denmark with an unchanging number of members, with a fixed rate mortgage in 2010 through 2017. The independent variables are indicated in the rows. The first set of variables is a set of dummy variables indicating the demographic status indicated in the row headers. The next set constitutes rank variables, which are normalized to take values between 0 and 1, and range between -0.5 and 0.5 once demeaned. All variables are described in greater detail in the header to Table 3 in the paper. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households. We use predicted mortgage terminations by household characteristics for all of our estimations of refinancing choices.

	2010	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
Single male household	0.308***	0.292***	0.285***	0.203***	0.208***	0.198***	0.164***	0.151***
Single female household	0.176***	0.157***	0.158***	0.097***	0.143***	0.130***	0.086***	0.047***
Married household	-0.378***	-0.409***	-0.396***	-0.470***	-0.366***	-0.466***	-0.481***	-0.470***
Children in family	-0.292***	-0.317***	-0.267***	-0.330***	-0.301***	-0.336***	-0.391***	-0.369***
Immigrant	0.285***	0.290***	0.251***	0.284***	0.193***	0.263***	0.262***	0.279***
Financially literate	-0.052***	0.002	0.016	-0.030**	0.012	0.002	0.001	-0.033***
Family financially literate	0.002	0.009	0.021**	0.040***	0.040***	0.042***	0.041***	0.018**
Getting married	0.173***	0.270***	0.261***	0.319***	0.299***	0.331***	0.312***	0.314***
Having children	0.133***	0.197***	0.204***	0.251***	0.223***	0.193***	0.268***	0.206***
Region of Northern Jutland	-0.199***	-0.221***	-0.130***	-0.222***	-0.071***	-0.230***	-0.221***	-0.149***
Region of Middle Jutland	-0.129***	-0.174***	-0.079***	-0.159***	-0.042***	-0.152***	-0.130***	-0.128***
Region of Southern Denmark	-0.148***	-0.165***	-0.092***	-0.177***	-0.129***	-0.207***	-0.174***	-0.196***
Region of Zealand	-0.114***	-0.157***	-0.067***	-0.133***	-0.147***	-0.193***	-0.159***	-0.119***
Demeaned rank of:								
Age	-1.431***	-1.514***	-1.476***	-1.698***	-1.651***	-1.671***	-1.651***	-0.000***
Length of education	0.055***	0.097***	0.061***	0.057***	0.133***	0.102***	0.082***	0.076***
Income	-0.840***	-0.828***	-0.884***	-0.734***	-0.473***	-0.526***	-0.529***	-0.000***
Financial wealth	0.036***	-0.072***	-0.124***	-0.158***	-0.081***	-0.181***	-0.159***	-0.000***
Housing wealth	-3.402***	-3.552***	-3.253***	-3.326***	-3.039***	-2.806***	-2.909***	-0.000***
Non-linear transformation f(x),where x is the demeaned rank of:								
Age	1.349***	1.401***	1.465***	1.619***	1.554***	1.849***	1.839***	0.000***
Length of education	0.152***	0.244***	0.234***	0.177***	0.076***	0.052**	0.108***	0.061***
Income	-0.099***	-0.127***	-0.146***	-0.199***	-0.086***	0.020	0.007	-0.000***
Financial wealth	1.584***	1.505***	1.366***	1.314***	1.125***	1.310***	1.355***	0.000***
Housing wealth	4.117***	4.363***	4.115***	4.061***	3.370***	3.310***	3.342***	0.000***
Constant	-2.144***	-2.099***	-2.066***	-1.754***	-1.744***	-1.816***	-1.788***	4.123***
Issuing quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Current quarter dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.104	0.107	0.118	0.102	0.111	0.107	0.108	0.1152
Log Likelihood	-382,319	-380,473	-379,302	-388,177	-442,534	-410,228	-404,948	-397,304
# of observations	1,251,582	1,265,265	1,266,556	1,263,575	1,279,920	1,247,412	1,231,344	1,241,651

Table B2: Underlying Distribution of Incentives

In each block of numbers, we compute the percentiles of the distribution reported in the top row of column headings, across the entire sample of Danish households pooling data over all periods from 2010 to 2017, as well as separately by year. The blocks of numbers are for the interest rate spread in percentage points (defined as the coupon rate on the old mortgage less the yield on a newly available mortgage of roughly the same maturity); the threshold level above which refinancing is sensible, taking into account the option value of waiting, reported in percentage points, and calculated using the closed form solution in the Agarwal et al. (2013) formula; and the total incentive in percentage points, measured as the interest rate spread less the computed threshold level. To preserve confidentiality, percentiles are calculated using 5 nearest observations to the percentile point.

	1%	5%	25%	Median	75%	95%	99%
				Interest Rate Spread in Percentage Points			
All	-1.06	-0.57	0.09	0.68	1.32	2.82	4.00
2010	-0.67	-0.67	0.31	0.69	0.95	2.01	3.01
2011	-1.05	-1.06	-0.23	0.22	0.86	1.86	3.03
2012	0.00	0.12	0.50	0.87	1.54	2.68	3.87
2013	-0.74	-0.28	0.39	0.72	1.46	2.73	3.88
2014	-0.56	-0.19	0.44	0.90	1.40	2.85	4.16
2015	-1.01	-0.73	-0.01	0.80	1.37	3.29	4.30
2016	-0.69	-0.68	-0.11	0.39	1.32	2.89	4.32
2017	-0.68	-0.26	-0.13	0.35	0.98	2.97	4.34
				Threshold Level in Percentage Points			
All	0.48	0.55	0.64	0.75	0.92	1.45	2.82
2010	0.50	0.56	0.65	0.75	0.93	1.49	2.71
2011	0.51	0.57	0.66	0.77	0.94	1.52	3.06
2012	0.49	0.56	0.65	0.76	0.95	1.57	3.61
2013	0.48	0.54	0.64	0.75	0.92	1.47	2.98
2014	0.48	0.54	0.64	0.75	0.94	1.48	2.99
2015	0.47	0.54	0.63	0.73	0.91	1.40	2.45
2016	0.47	0.54	0.63	0.73	0.90	1.34	2.46
2017	0.48	0.54	0.64	0.73	0.89	1.33	2.60
				Incentives in Percentage Points			
All	-2.06	-1.45	-0.72	-0.13	0.44	1.63	2.58
2010	-2.06	-1.40	-0.76	-0.14	0.24	1.18	1.90
2011	-2.65	-1.88	-1.15	-0.68	0.02	0.84	1.61
2012	-2.22	-0.85	-0.33	0.07	0.68	1.52	2.37
2013	-1.91	-1.18	-0.50	-0.04	0.55	1.56	2.44
2014	-1.77	-1.10	-0.34	0.11	0.67	1.78	2.61
2015	-1.94	-1.57	-0.75	0.01	0.76	2.12	3.00
2016	-1.84	-1.42	-0.81	-0.25	0.44	1.91	2.85
2017	-1.71	-1.23	-0.80	-0.31	0.26	1.84	2.81

Table B3: Differences in Household Characteristics: Refinancing and Non-Refinancing Households

The first column shows the average of each of the characteristics reported in the rows, pooled across the entire sample from 2010-2017. Columns 2 to 7 report the difference of means between refinancing and non-refinancing households, with a negative value indicating a lower mean for refinancing households. Differences are reported either unconditionally across the entire sample (Column "All"), or conditional on the sub-periods in the column headers. In the rows, "single" households (male or female) have only one adult living at the address, and represent ~13% of the entire sample. "Married" households have two legally bound adults (including registered partnership of same-sex couples). "Children in family" takes the value of one if there are children in the household. "Immigrant" takes the value of one if there is an immigrant in the household. "No educational information" indicates an absence of data on this attribute. "Financially literate" takes the value of one if a member of the household has a degree in finance, or has had professional financial industry training. "Family financially literate" indicates when (non-household-resident) parents, siblings, in-laws, or children of the household are financially literate. "Getting married" refers to that change in marital status over the sample period. "Having children" indicates that households had a child within the last 12 months. "Rank of age" uses the age of the oldest person living in the household. "Rank of education" uses the best educated individual in the household. "Rank of income (financial wealth, housing assets)" uses the total income (financial wealth, housing assets) of the household. All ranks are computed each year across all households in the sample, and are normalized such that they take values between -0.5 and 0.5. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level by standard t-tests, respectively.

		Difference between Refinancing and Non-Refinancing Households								
	Average	All	2010	2011	2012	2013	2014	2015	2016	2017
Single male household	0.128	-0.032***	-0.035***	-0.030***	-0.038***	-0.022***	-0.036***	-0.030***	-0.025***	-0.031***
Single female household	0.123	-0.023***	-0.030***	-0.025***	-0.021***	-0.012***	-0.027***	-0.021***	-0.018***	-0.028***
Married household	0.626	0.034***	0.020***	0.027***	0.039***	0.042***	0.051***	0.042***	0.020***	0.018***
Children in family	0.409	0.079***	0.106***	0.075***	0.078***	0.035***	0.081***	0.072***	0.070***	0.101***
Immigrant	0.080	-0.001	0.001	-0.001***	0.002**	0.005***	-0.007***	0.002*	0.001*	-0.003***
Financially literate	0.056	0.014***	0.001***	0.013***	0.016***	0.019***	0.019***	0.017***	0.018***	0.015***
Family financially literate	0.163	0.029***	0.020***	0.023***	0.034***	0.036***	0.038***	0.032***	0.034***	0.032***
Getting married	0.010	0.005***	0.009***	0.005***	0.005***	-0.001***	0.001***	0.004***	0.004***	0.002***
Having children	0.043	0.018***	0.032***	0.025***	0.018***	0.004***	0.009***	0.012***	0.015***	0.026***
Rank of age	0.000	-0.060***	-0.099***	-0.065***	-0.056***	-0.002***	-0.045***	.0.044***	-0.057***	-0.088***
Rank of education	0.000	0.042***	0.031***	0.023***	0.048***	0.044***	0.046***	0.048***	0.047***	0.054***
Rank of income	0.001	0.001***	0.060***	0.047***	0.063***	0.050***	0.069***	0.060***	0.062***	0.078***
Rank of financial wealth	0.001	-0.049***	-0.099***	-0.077***	-0.045***	0.004***	-0.027***	-0.029***	-0.033***	-0.061***
Rank of housing value	-0.001	0.051***	0.027***	0.027***	0.057***	0.086***	0.058***	0.059***	0.054***	0.060***
Region North Jutland	0.127	-0.005***	0.002***	-0.067***	-0.006***	-0.042***	0.025***	-0.009***	-0.014***	-0.010***
Region Middle Jutland	0.239	0.010***	0.022***	0.014***	0.019***	0.002***	0.024***	0.001***	-0.004**	-0.010***
Region Southern Denmark	0.232	-0.014***	-0.003*	0.017***	-0.015***	0.032***	0.011***	-0.021***	-0.018***	-0.024***
Region Zealand	0.183	-0.018***	-0.012***	-0.023***	-0.019***	-0.003***	-0.047***	-0.013***	-0.018***	0.013***
Region Copenhagen	0.219	0.027***	-0.008***	-0.002***	0.022***	0.078***	0.001***	0.043***	0.054***	0.056***
# of observations	9,351,183	9,351,183	1,245,273	1,178,033***	1,178,468***	1,075,044***	1,093,582***	1,123,203	1,285,315	1,296,648

Table B4: Underlying Distribution of Ranked Variables

The percentiles of the distribution reported in the column headings are calculated across the sample of all households in Denmark with a single fixed rate mortgage, pooling data over 2010 through 2017. The blocks of statistics are presented for income (total taxable income for each household in million DKK); financial wealth (the value of cash, bonds, stocks, and mutual funds less non-mortgage debt, in million DKK); Housing value (the value of properties, in million DKK); education (the number of years it takes to reach the highest level of education possessed by any individual in the household, where a rule of thumb is that 12 years is a high school diploma, 16 is a Bachelor's degree, 18 is a Master's degree, and 20 is a PhD); and age (measured in calendar years). Within each block of statistics, percentiles are calculated for all households, and separately for the sub-populations of refinancing and non-refinancing households. To preserve confidentiality, percentiles are calculated as the average of the five nearest observations to the percentile point.

	1%	5%	25%	Median	75%	95%	99%
				Income			
All	0.150	0.205	0.386	0.604	0.796	1.184	1.739
Refinancing	0.163	0.245	0.447	0.657	0.839	1.245	1.833
Non-refinancing	0.150	0.200	0.377	0.591	0.786	1.171	1.720
				Financial Wealth			
All	-1.400	-0.644	-0.192	0.033	0.238	0.952	2.278
Refinancing	-1.440	-0.717	-0.267	-0.011	0.188	0.877	2.219
Non-refinancing	-1.393	-0.626	-0.176	0.040	0.248	0.965	2.290
				Housing Wealth			
All	0.364	0.542	0.938	1.356	1.983	3.440	5.783
Refinancing	0.417	0.618	1.029	1.500	2.138	3.615	5.924
Non-refinancing	0.355	0.530	0.917	1.324	1.958	3.400	5.744
				Education			
All	8	9	14	15	17	18	21
Refinancing	8	10	14	15	17	18	21
Non-refinancing	8	8	14	15	17	18	21
				Age			
All	26	31	42	53	63	76	85
Refinancing	26	30	40	49	61	74	82
Non-refinancing	26	31	43	53	64	77	85

Table B5: Differences in Household Characteristics: Refinancing and Non-Refinancing Households Conditional on Incentives

The first (third) column shows the average of each of the characteristics reported in the rows, for individuals with positive (negative) incentives. Columns 2 (4) reports the difference of means between refinancing and non-refinancing households among households with a positive (negative) inventive, with a negative value indicating a lower mean for refinancing households. Differences are reported either unconditionally across the entire sample (Column "All"), or conditional on the sub-periods in the column headers. In the rows, "single" households (male or female) have only one adult living at the address, and represent ~13% of the entire sample. "Married" households have two legally bound adults (including registered partnership of same-sex couples). "Children in family" takes the value of one if there are children in the household. "Immigrant" takes the value of one if there is an immigrant in the household. "No educational information" indicates an absence of data on this attribute. "Financially literate" takes the value of one if a member of the household has a degree in finance, or has had professional financial industry training. "Family financially literate" indicates when (non-household-resident) parents, siblings, in-laws, or children of the household are financially literate. "Getting married" refers to that change in marital status over the sample period. "Having children" indicates that households had a child within the last 12 months. "Rank of age" uses the age of the oldest person living in the household. "Rank of education" uses the best educated individual in the household. "Rank of income (financial wealth, housing assets)" uses the total income (financial wealth, housing assets) of the household. All ranks are computed each year across all households in the sample, and are normalized such that they take values between -0.5 and 0.5. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level by standard t-tests, respectively.

Difference between Refinancing and Non-Refinancing Households

	Positive incentives		Negative incentives	
	Average	Difference	Average	Difference
Single male household	0.128	-0.037***	0.128	-0.012***
Single female household	0.126	-0.029***	0.120	-0.012***
Married household	0.635	0.040***	0.620	-0.019***
Children in family	0.395	0.101***	0.420	0.046***
Immigrant	0.081	-0.002***	0.079	-0.001
Financially literate	0.049	0.021***	0.061	0.016***
Family financially literate	0.149	0.042***	0.173	0.026***
Getting married	0.008	0.006***	0.012	0.008***
Having children	0.038	0.021***	0.048	0.026***
Rank of age	0.029	-0.084***	-0.022	-0.074***
Rank of education	-0.016	0.063***	0.012	0.022***
Rank of income	-0.014	0.084***	0.013	0.032***
Rank of financial wealth	0.002	-0.046***	-0.003	-0.079***
Rank of housing value	-0.008	0.065***	0.005	0.027***
Region North Jutland	0.122	-0.001***	0.131	-0.008***
Region Middle Jutland	0.230	0.001***	0.246	0.001***
Region Southern	0.230	-0.014***	0.233	-0.008***
Region Zealand	0.200	-0.034***	0.194	-0.019***
Region Copenhagen	0.217	0.027***	0.220	0.034***
# of observations	4,090,253	4,090,253	5,260,930	5,260,930

Table B6: Counterfactual Interest Rate Saving from Refinancing

This table estimates the counterfactual saving that would prevail if households refinanced optimally, and compares this estimate to the actual saving arising from household refinancing. Counterfactual savings are calculated assuming that the household refinances instantly every time it has positive incentives to do so, and computed as the saved interest rate net of the annuitized cost of refinancing. In these counterfactual calculations, we assume that the coupon on the new mortgage is the closest available coupon below the current market yield. For instance, if the market yield is 4.2 percent, we assume that households refinance into a mortgage bearing a coupon of 4 percent. In cases in which the counterfactual policy implies that households refinance multiple times, we simply accumulate savings from multiple rounds of refinancing. In contrast, actual savings from refinancing are calculated as the saved interest rate arising from the refinancing policy that the household actually implemented, net of the annuitized incurred cost of refinancing. Missed savings is simply the difference between counterfactual and actual savings, and we show both actual and missed savings in the table below. The column headers list the units in which savings are measured, namely, savings as a percentage of the mortgage principal, in 1,000 DKK, and savings as a percentage of household income. The top panel reports these statistics by year, and the following panels report these statistics for quintiles of the population sorted by age, education, income, financial wealth, and housing wealth, with 1 representing the bottom and 5 the top group in each distribution – with the corresponding quintile means in the extreme right hand column.

	%		*1,000 DKK*		*% of income*		
	Actual	*Missed*	*Actual*	*Missed*	*Actual*	*Missed*	*N*
			Actual vs. missed interest rate savings from refinancing by year				
All	0.55	0.43	6.0	2.7	0.97	0.58	2,376,815
2010	0.10	0.42	1.2	3.3	0.21	0.61	330,350
2011	0.16	0.40	1.9	2.9	0.32	0.55	297,445
2012	0.36	0.45	4.0	2.8	0.67	0.57	277,204
2013	0.46	0.54	5.2	3.6	0.86	0.75	274,464
2014	0.58	0.47	6.2	2.7	1.04	0.63	264,767
2015	0.92	0.56	10.1	3.6	1.62	0.80	276,308
2016	0.87	0.37	9.6	2.0	1.52	0.49	321,611
2017	0.88	0.26	9.6	0.9	1.50	0.32	334,666
2017, Q4	0.89	0.25	9.7	0.7	1.52	0.31	312,043

	%		*1,000 DKK*		*% of income*		
Quintiles	*Actual*	*Missed*	*Actual*	*Missed*	*Actual*	*Missed*	*Average char.*
			Actual vs. missed interest rate savings from refinancing by age				
1	0.48	0.28	6.5	2.7	0.94	0.48	33.8
2	0.59	0.34	7.7	2.7	1.01	0.47	44.3
3	0.56	0.43	6.2	2.6	0.89	0.49	52.7
4	0.56	0.48	5.3	2.6	0.92	0.55	61.3
5	0.54	0.60	4.4	2.8	1.11	0.91	73.7

Actual vs. missed interest rate savings from refinancing by education

1	0.50	0.60	4.0	2.9	0.94	0.86	10
2	0.55	0.45	5.3	2.7	0.99	0.63	14
3	0.55	0.45	5.5	2.7	0.97	0.58	15
4	0.53	0.35	6.4	2.7	0.93	0.47	16
5	0.60	0.29	8.9	2.4	1.04	0.38	18

Actual vs. missed interest rate savings from refinancing by income

1	0.46	0.67	3.2	2.9	1.13	1.18	251.0
2	0.52	0.49	4.4	2.8	1.00	0.68	426.5
3	0.56	0.40	5.7	2.7	0.93	0.46	599.7
4	0.59	0.33	7.1	2.6	0.93	0.35	755.1
5	0.59	0.25	9.8	2.5	0.89	0.24	1,127.4

Actual vs. missed interest rate savings from refinancing by financial wealth

1	0.52	0.36	6.6	3.3	0.93	0.57	-629.6
2	0.55	0.40	6.0	2.7	1.00	0.59	-135.1
3	0.54	0.49	5.3	2.6	1.04	0.71	33.6
4	0.57	0.43	6.0	2.3	1.00	0.53	191.1
5	0.54	0.46	6.2	2.5	0.90	0.51	923.0

Actual vs. missed interest rate savings from refinancing by housing wealth

1	0.47	0.61	3.0	2.4	0.71	0.68	634.0
2	0.55	0.47	4.6	2.7	0.93	0.63	1,009.5
3	0.58	0.40	6.0	2.7	1.04	0.58	1,354.0
4	0.57	0.34	7.3	2.8	1.09	0.53	1,847.6
5	0.56	0.31	9.3	2.9	1.11	0.48	3,350.5

Table B7: Summary Statistics of Estimated Model Parameters

This table shows summary statistics of the estimated model parameters across the entire sample period. In the top panel, we show the mean, median, and standard deviation of the estimated probability of being asleep; the estimated psychological costs in 1,000 DKK; the calculated ADL 2013 refinancing threshold level in basis points; the increment to the ADL threshold arising from estimated psychological costs; and the total threshold which is the sum of the previous two components. In the bottom panel, we show the correlation matrix of these different parameters from the model.

	Mean	Median	Standard Dev.
Asleep probability	0.86	0.90	0.11
Psychological costs in 1,000 DKK	10.35	8.96	5.77
Optimal ADL refinancing threshold	82.63	74.79	28.13
Psychological increment to threshold	68.69	54.17	55.72
Total threshold	151.32	130.95	76.25

Correlation Matrix

	Asleep probability	Psychological costs in 1,000 DKK	Optimal ADL threshold	Psychological increment to threshold	Total threshold
Asleep probability	1.000				
Psychological costs in 1,000 DKK	-0.656	1.000			
Optimal ADL refinancing threshold	0.033	-0.025	1.000		
Psychological increment to threshold	-0.002	0.019	0.870	1.000	
Total threshold	0.006	0.010	0.920	0.994	1.000

Table B8: Restricted Models

We estimate these specifications using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in any year from 2010 to 2017. In all specifications, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. Specification (1) is our baseline model presented in Table 3, in which demographics affect φ and χ. Specification (2) is a simple model in which demographics do not affect φ and χ, but the model does include dummies for the current quarter, as well as dummies for mortgage age in years. In specification 3 (4) we only allow demographics to affect φ (χ). In specification 5, demographics affect both χ and φ, but in a manner which is constrained to be proportional. As before, these models include non-linear transformations, f(x), of several of the rank control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being awake. The Log Likelihood reduction is calculated in each case as the difference between the log likelihood of the baseline model (specification (1)), and the log likelihood of the model corresponding to each row. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

Specification	Pseudo R2	Log likelihood difference	χ	φ
(1)	0.069		Free	Free
(2)	0.052	-23637	None	None
(3)	0.063	-9000	None	Free
(4)	0.063	-9024	Free	None
(5)	0.064	-7612	Proportional	Proportional

Figure B1: Histogram of Estimated Mortgage Termination Probabilities

This figure shows our estimated mortgage termination probabilities. To compute these estimates, we fit a simple probit model to realized mortgage terminations using all households with a single fixed-rate mortgage, conditioning the dummy variable for mortgage termination on household characteristics. We plot the fitted values from this probit model, with a dark dashed line at 10%, which is the Agarwal et al. (2013) suggested "hardwired" value.

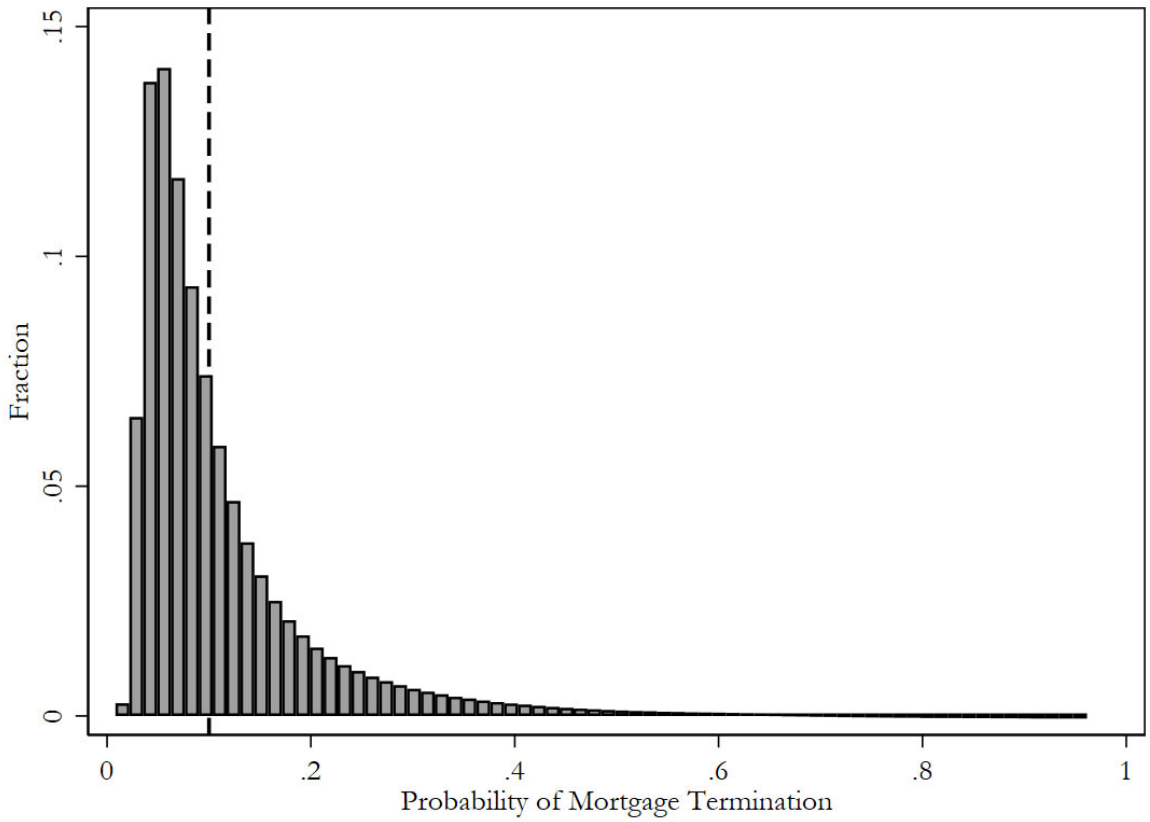


Figure B2: 30-year Danish Mortgage Rates, 2003-2017

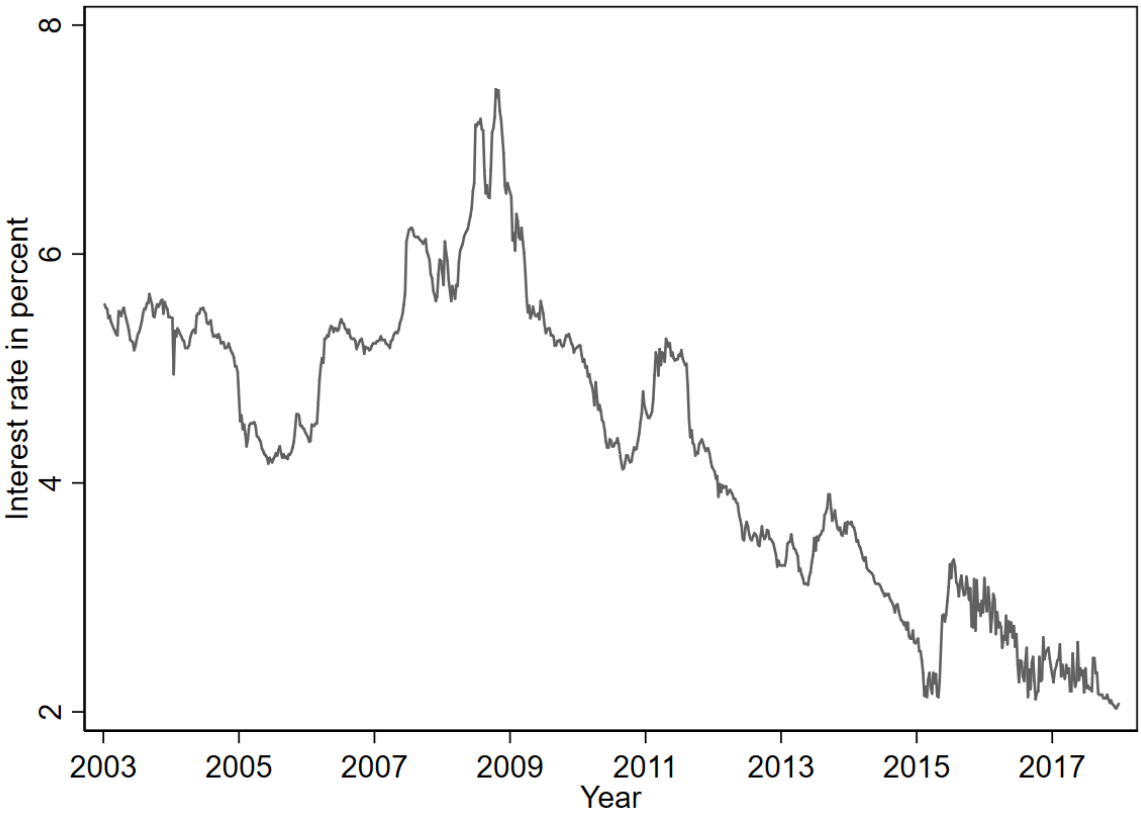


Figure B3: House and apartment prices, 2003-2017

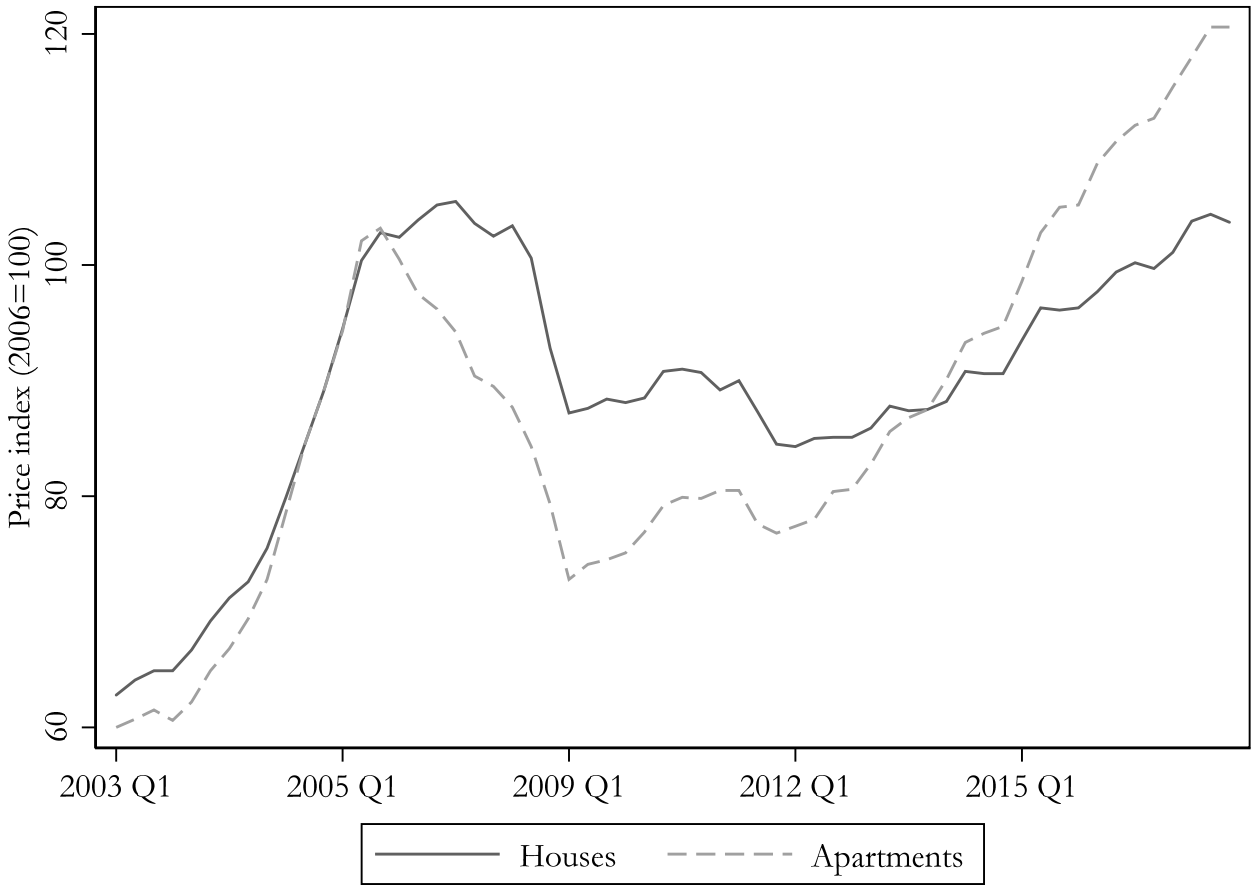


Figure B4: Refinancing Activity by New Mortgage Coupon Rates

This figure illustrates the history of refinancing activity in our sample of Danish fixed-rate mortgages. The bars represent the number of refinancing households. The figure shades each of the bars according to the coupon rate on the new fixed rate mortgage into which households refinance. The bars labelled "non-FRM" capture households with FRMs refinancing into ARMs, capped ARMs, or other floating-rate mortgages.

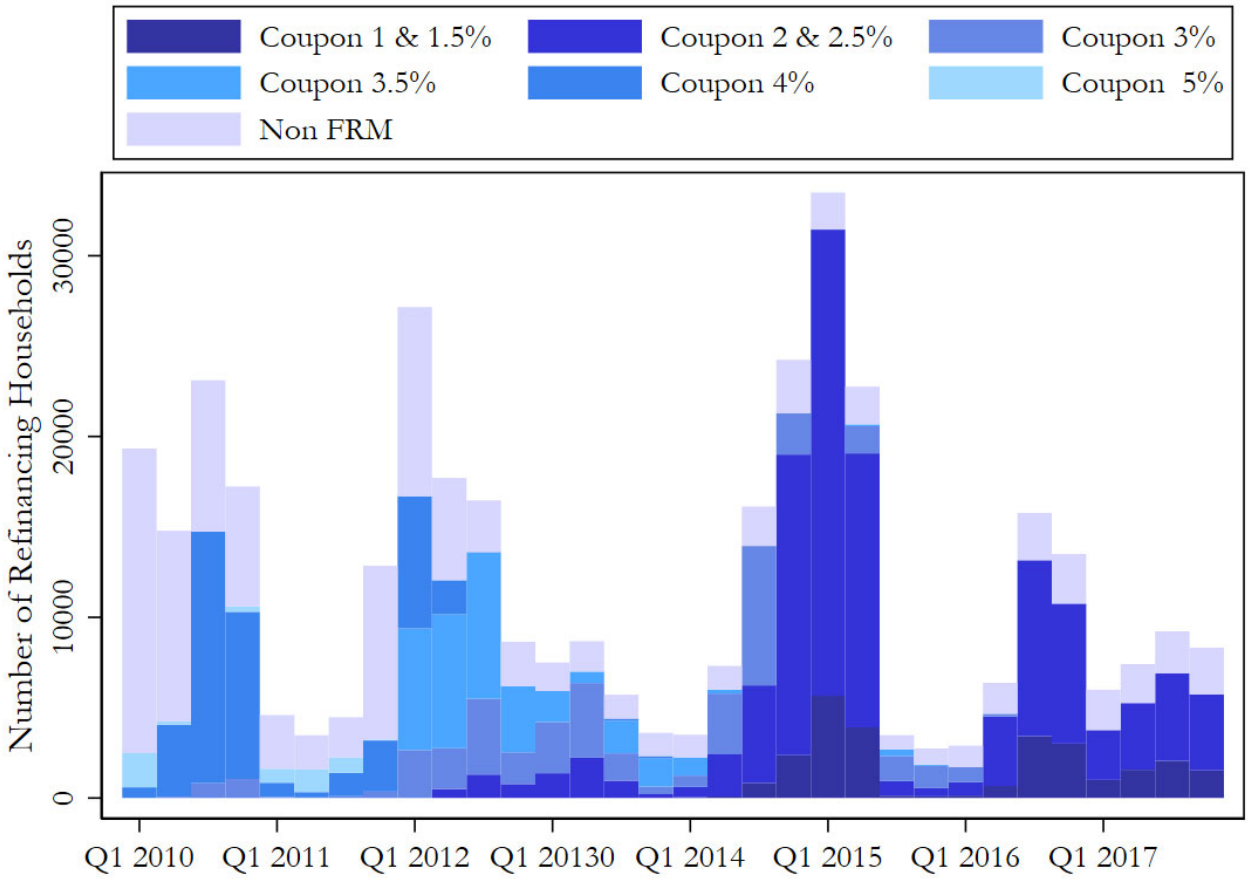


Figure B5: Fraction of Refinancing Households by Old Coupon Rate

This figure illustrates the history of refinancing activity in our sample of Danish fixed-rate mortgages. The bars represent the fraction of refinancing households by old coupon rate in each quarter.

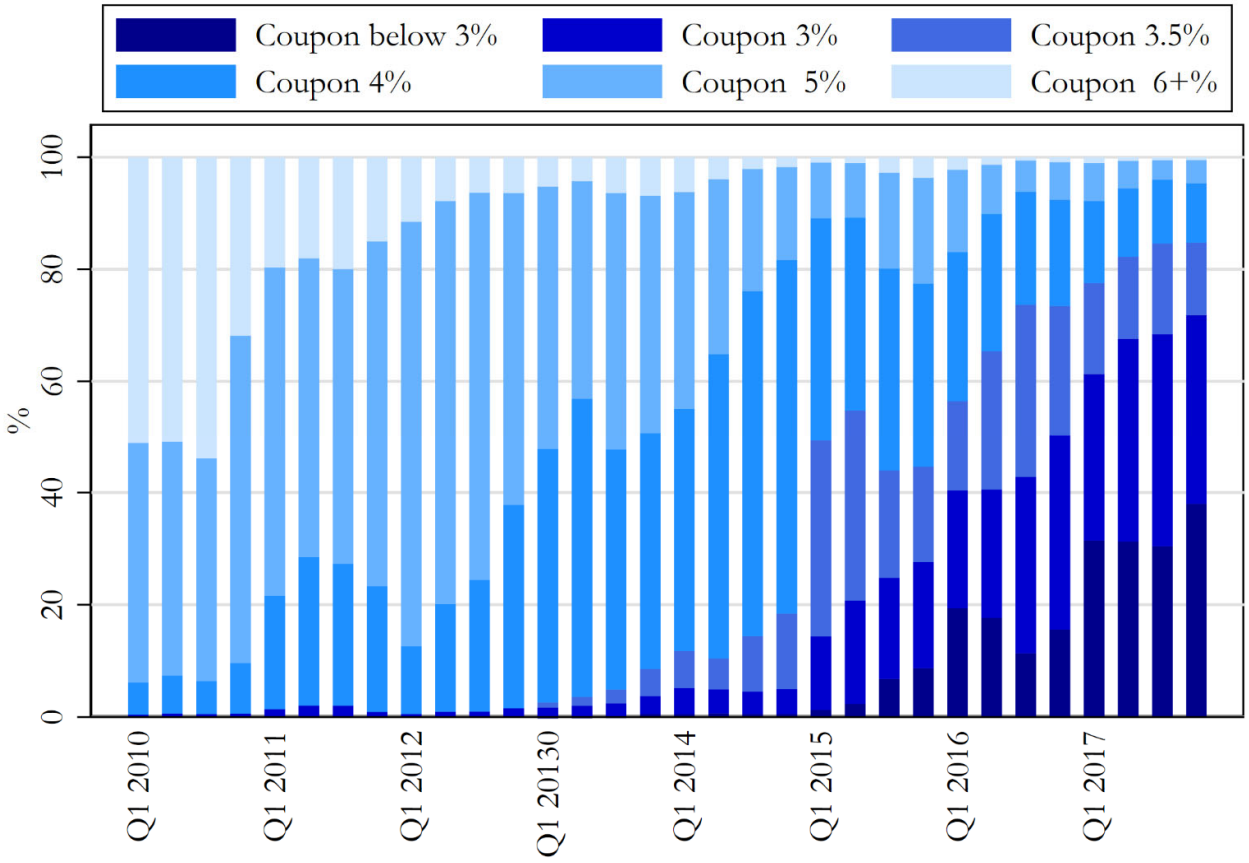
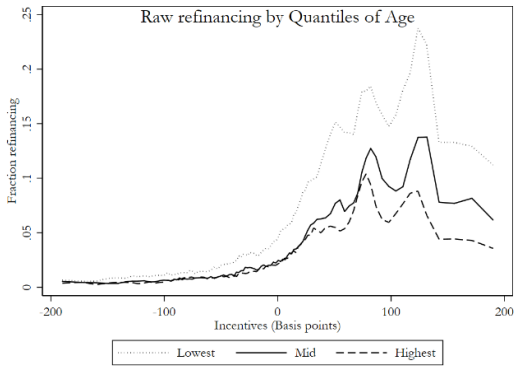
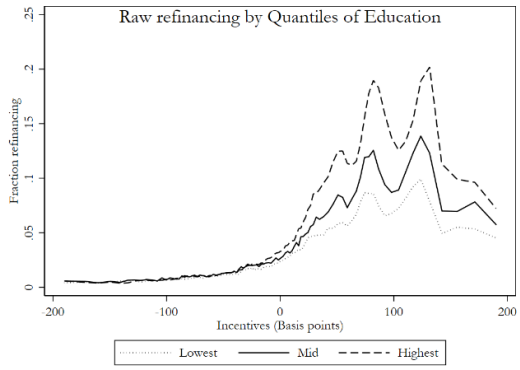
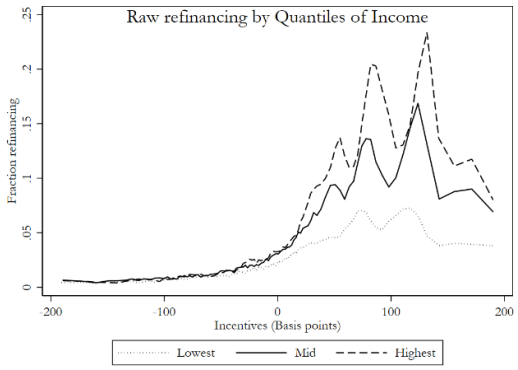


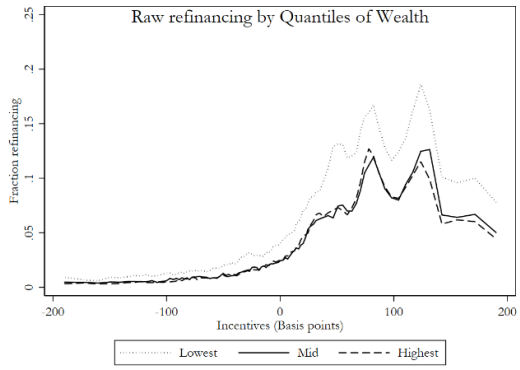
Figure B6: Raw Refinancing Fractions by Ranked Covariates

These figure plots refinancing probability over estimated ADL threshold levels (i.e., without the psychological increment to the threshold level) in basis points by separate our ranked variables. We plot the lowest (-20%), the mid (40-60%) and the highest (80%-) quantiles. The graphs are constructed by taking the average refinancing fraction by each centile of incentives.









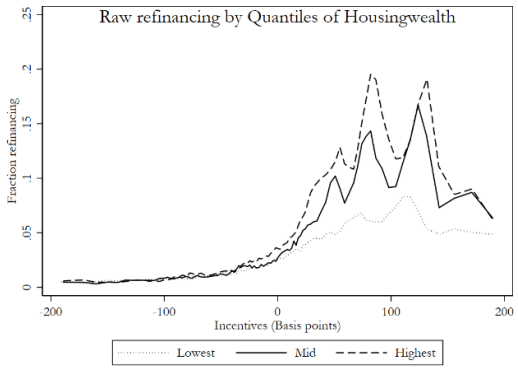


Figure B7: Raw Refinancing Fractions by Dummy Covariates

These figure plots refinancing probability over estimated ADL threshold levels (i.e., without the psychological increment to the threshold level) in basis points by our defined dummy variables. The baseline are all individuals with the dummy equal to 0. The graphs are constructed by taking the average refinancing fraction by each centile of incentives.

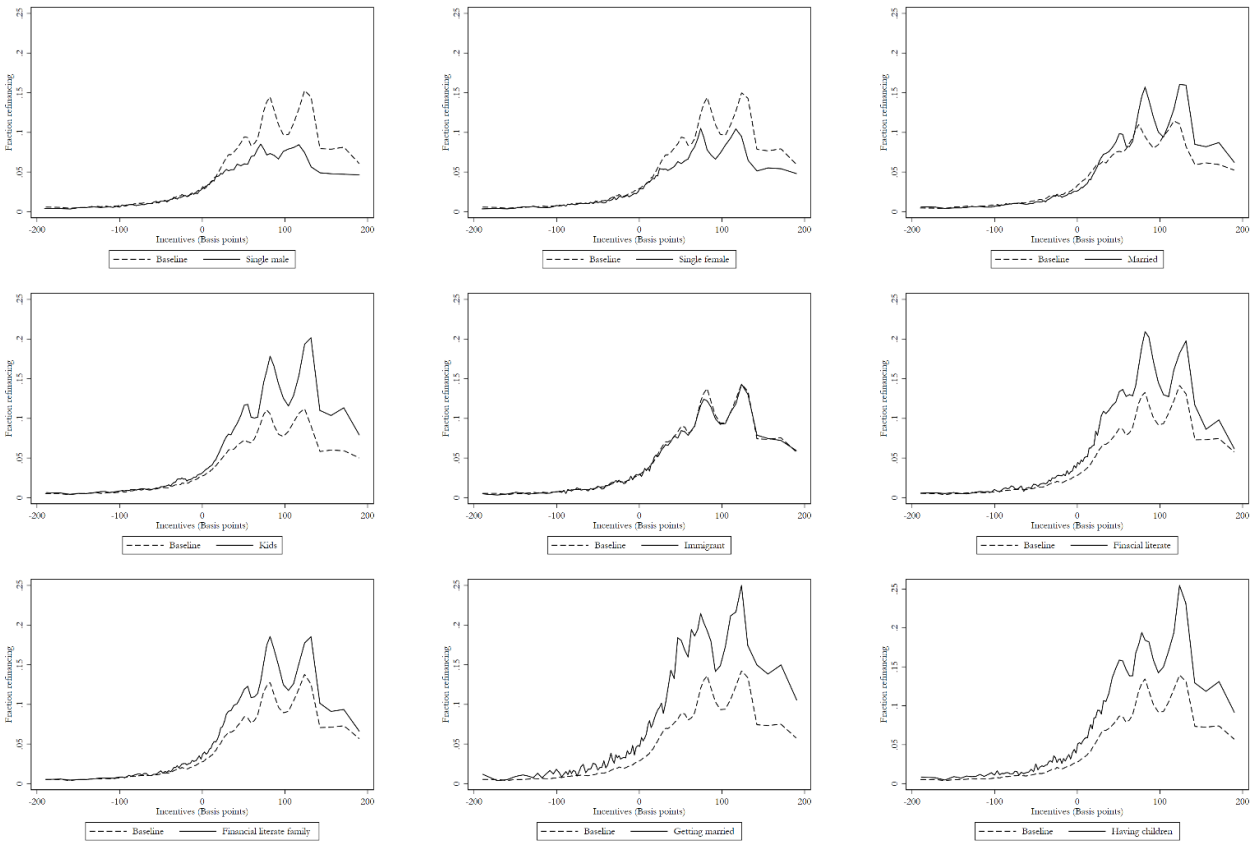


Figure B8: Refinancing Activity and Internet Search Activity

This figure illustrates the correlation between refinancing activity and internet search activity in each quarter of our sample of Danish fixed-rate mortgages. The bars (left vertical axis) represent the number of refinancing households, while the line (right vertical axis) represents the intensity of search activity using Google Trends data. We track Google search activity for "refinancing" keywords in Danish (i.e. "*konvertering*" and "*omlægning*") using a search index taking values from 0 to 100, where 100 indicates the most activity. We plot the average of the weekly search index over the quarter.

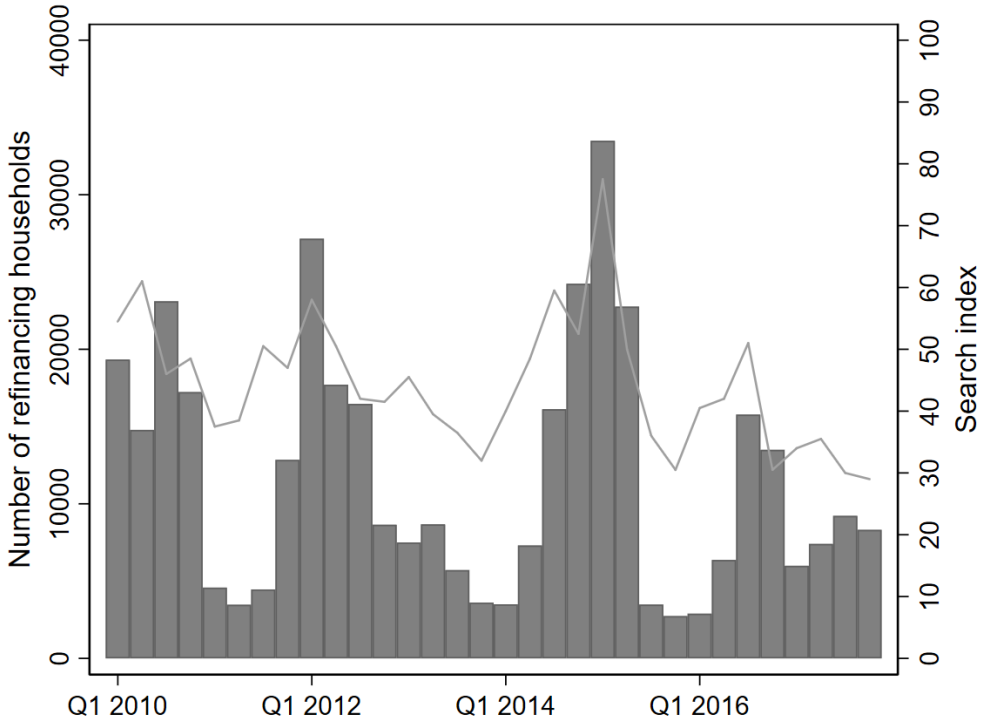


Figure B9: Model Implied Asleep Probability and Internet Search Activity

This figure illustrates the correlation between the model implied probability of households being asleep and internet search activity for each quarter of our sample of Danish fixed-rate mortgages. The bars (left vertical axis) represent the model implied probability of households being asleep estimated using the baseline model presented in Table 3. The line (right vertical axis) represents the intensity of internet search activity using Google Trends data. We track Google search activity for "refinancing" keywords in Danish (i.e. "*konvertering*" and "*omlægning*") using a search index taking values from 0 to 100, where 100 indicates the most activity. We plot the average of the weekly search index over the quarter.

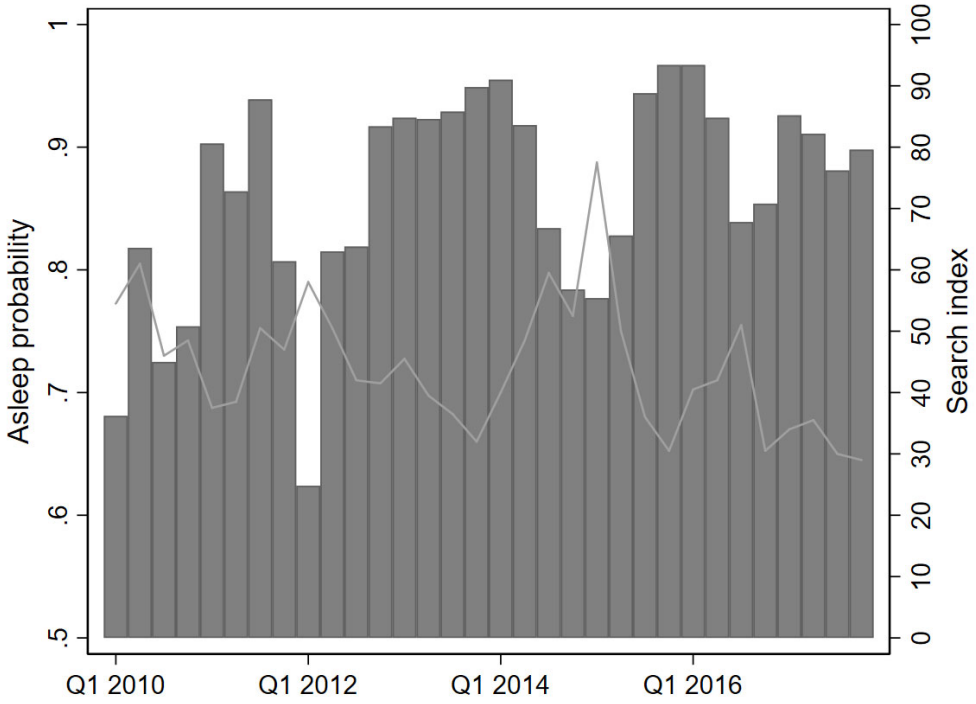
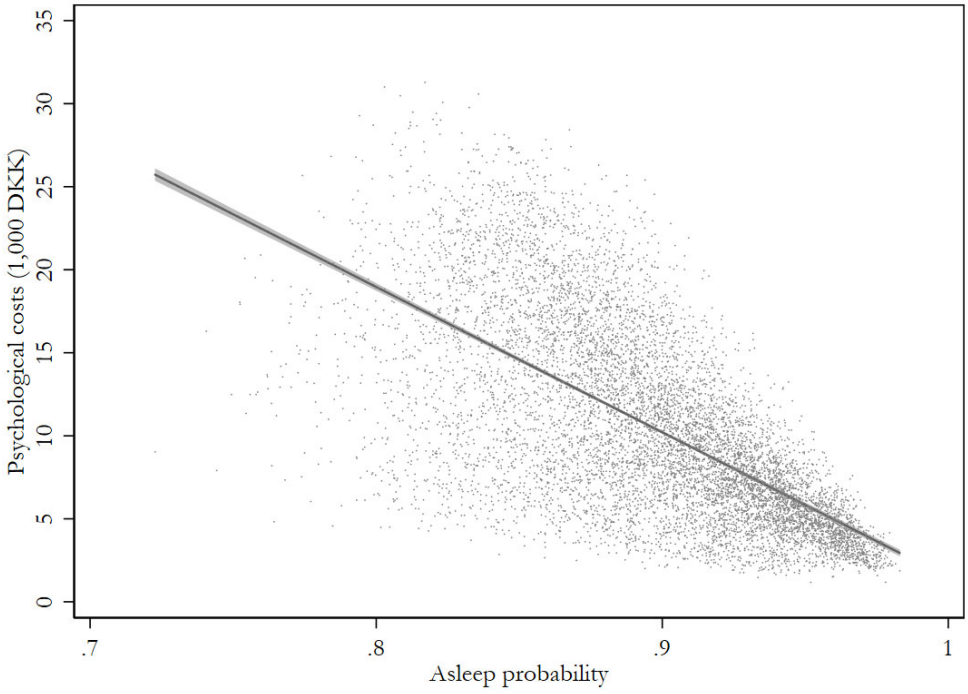


Figure B10: Proportionality of Coefficient Estimates

This figure plots household-level estimated psychological costs against the estimated probability of a household being asleep from the model in Table 3. The top panel plots these psychological costs in 1,000 DKK, while the bottom figure plots these psychological costs as the increment to the interest-rate threshold which needs to be surmounted to induce a household to refinance. Fitted coefficients are based on actual household demographic characteristics from a random 0.1% sample of all observations in our dataset. The solid line fits a univariate regression line (and associated standard error bands) to the cloud of points.



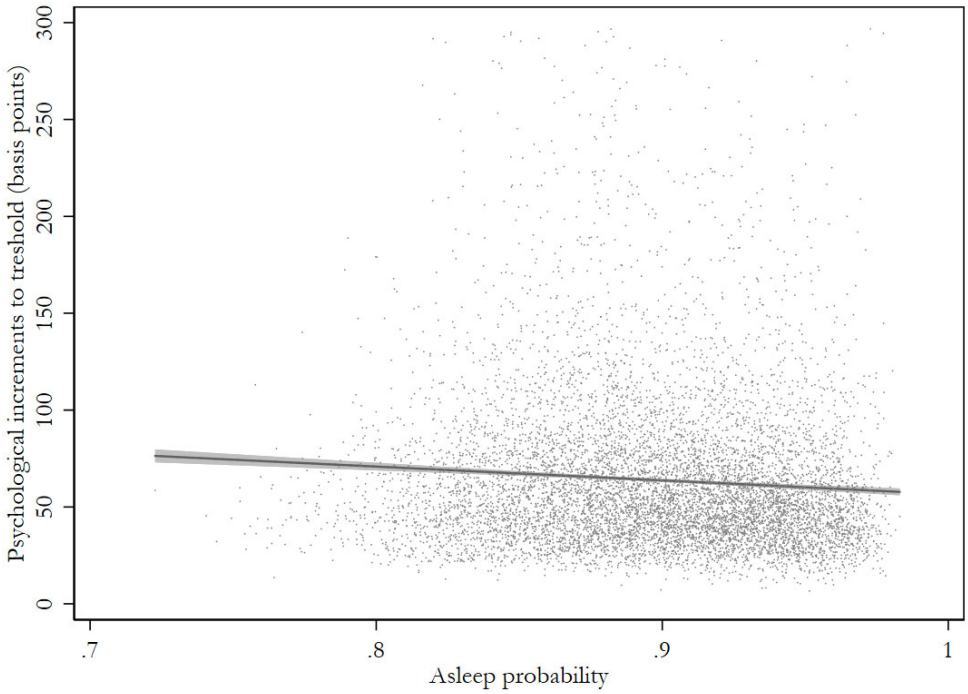
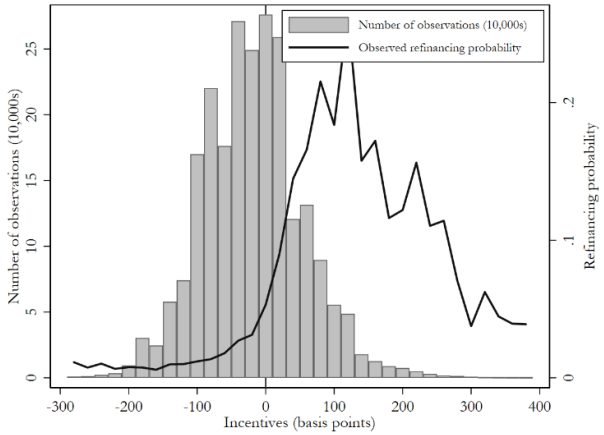
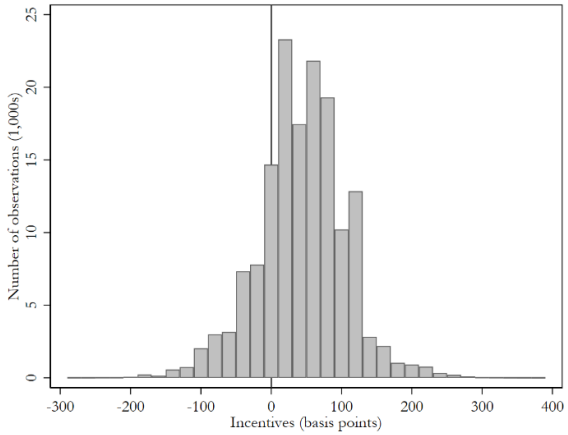


Figure B11: Refinancing Activity by Asleep Probability

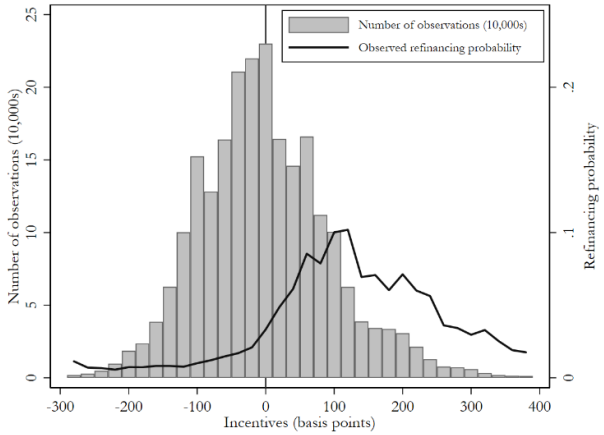
This figure illustrates refinancing activity in the sample evaluated against the household-quarter-specific ADL threshold. The left (right) column shows activity for the 25% of households with the lowest (highest) level of asleep probability, using model 10 in table 2 and variation in demographic characteristics to predict asleep probability. Within each column, the top plot shows the histogram of computed incentives with the refinancing probability superimposed on it; and the bottom plot shows the number of refinancings at each point corresponding to the dark line on the top plot.

Households with low with asleep probability





Households with high asleep probability



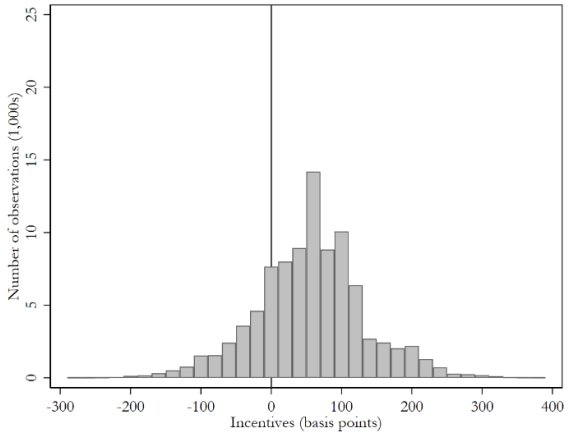
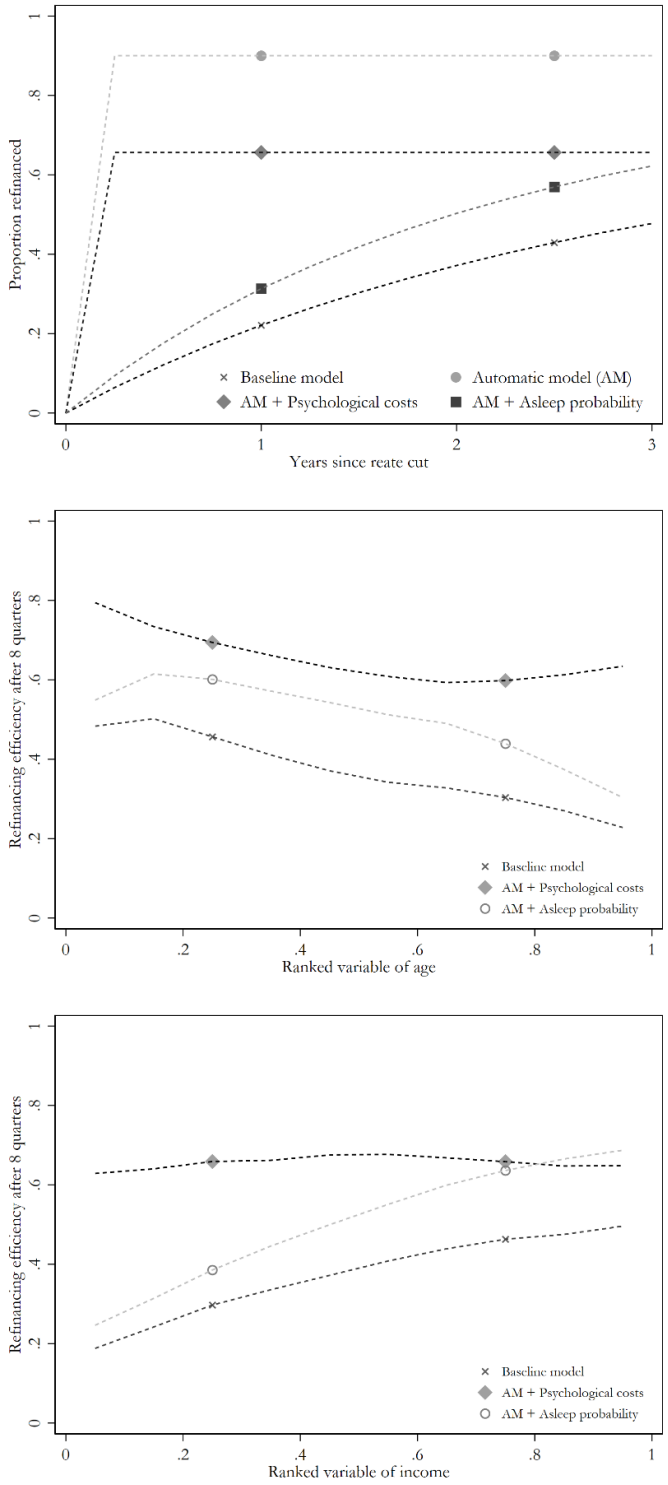


Figure B12: Model Experiments

These figures consider the effect of various features of the model in response to an interest rate cut in which 90% of Danish households have a refinancing incentive that exceeds their ADL (2013) threshold. We consider households that are fully rational, i.e., fully awake and with zero psych costs; households that are awake, but can have psych costs; households that are sometimes asleep, but with no psych costs; and the baseline model in which households can have psych costs and be asleep. The top panel of this figure shows the fraction of households that refinances at each point in time after the rate cut, and the second (third) the fraction of households that refinances 8 quarters after the interest rate cut at different points in the age (income) distribution.



Appendix C: Excluding Cash-out and Extension Refinancing
Table C1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix C specification we exclude all cash-out - and extension - refinanced mortgages. We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = $\exp(\varphi)$) as a function of demographic characteristics, and $\exp(\beta)$ captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.830***	2.678***	2.972***
Single male household		-0.118***	0.024
Single female household		-0.131***	-0.094***
Married household		0.121***	-0.046***
Children in family		0.099***	0.115***
Immigrant		-0.104***	0.174***
Financially literate		-0.143***	-0.017
Family financially literate		-0.006	-0.091***
Getting married		-0.228***	-0.066***
Having children		-0.088***	-0.092***
Region of Northern Jutland		0.093***	-0.291***
Region of Middle Jutland		0.065***	-0.227***
Region of Southern Denmark		0.021	-0.110***
Region of Zealand		0.050***	0.141***
Demeaned rank of:			
Age		-0.063**	0.778***
Length of education		0.089***	-0.249***
Income		0.798***	-0.793***
Financial wealth		0.795***	-0.279***
Housing wealth		0.574***	-0.789***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-1.407***	0.077***
Length of education		0.247***	-0.002
Income		-0.301***	0.599***
Financial wealth		-0.849***	0.173***
Housing wealth		-0.489***	0.359***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.072	
Log likelihood		-1,237,740	
Observations		9,082,396	

Figure C1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table C1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

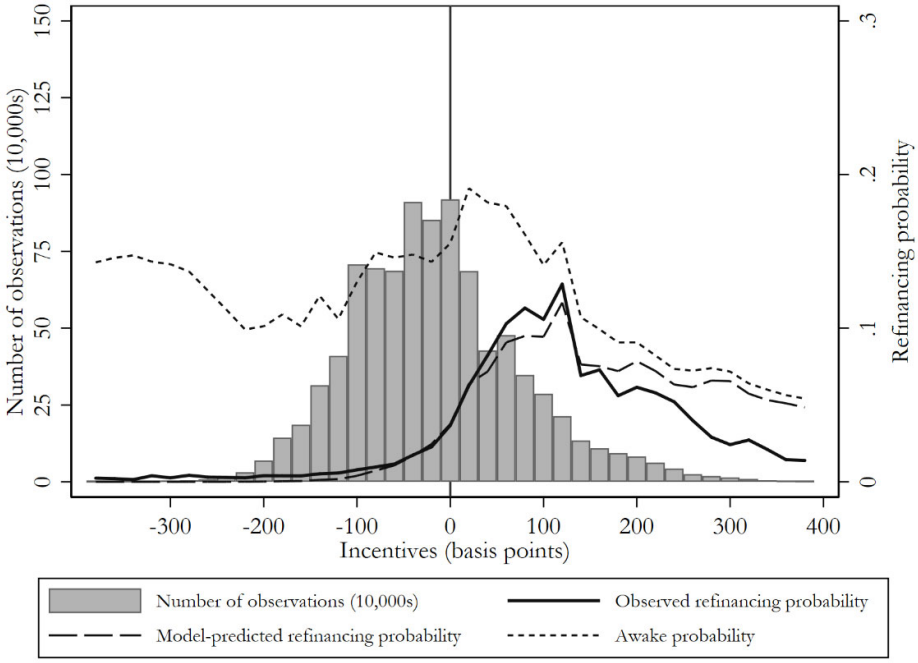


Figure C2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table C1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

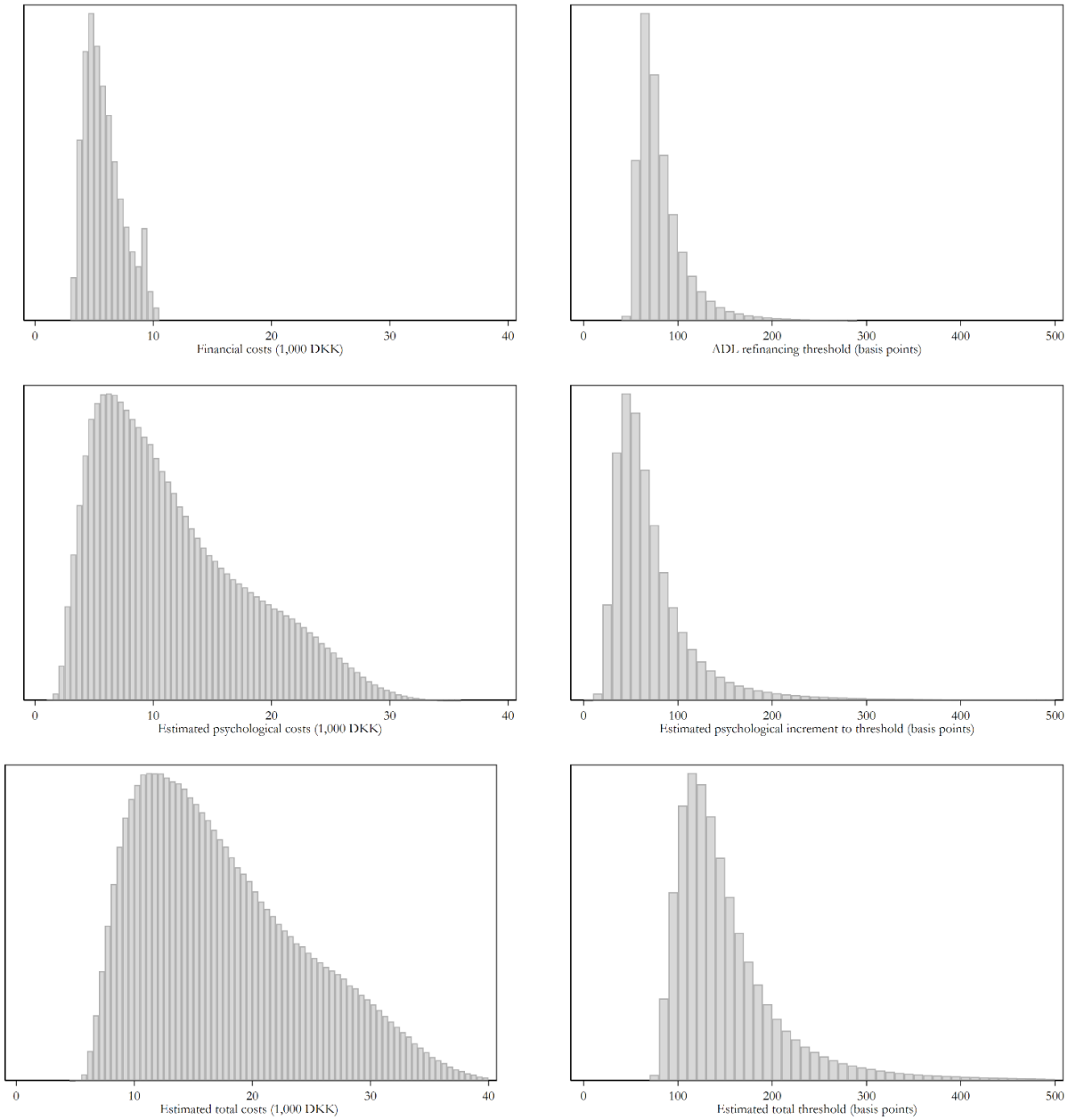
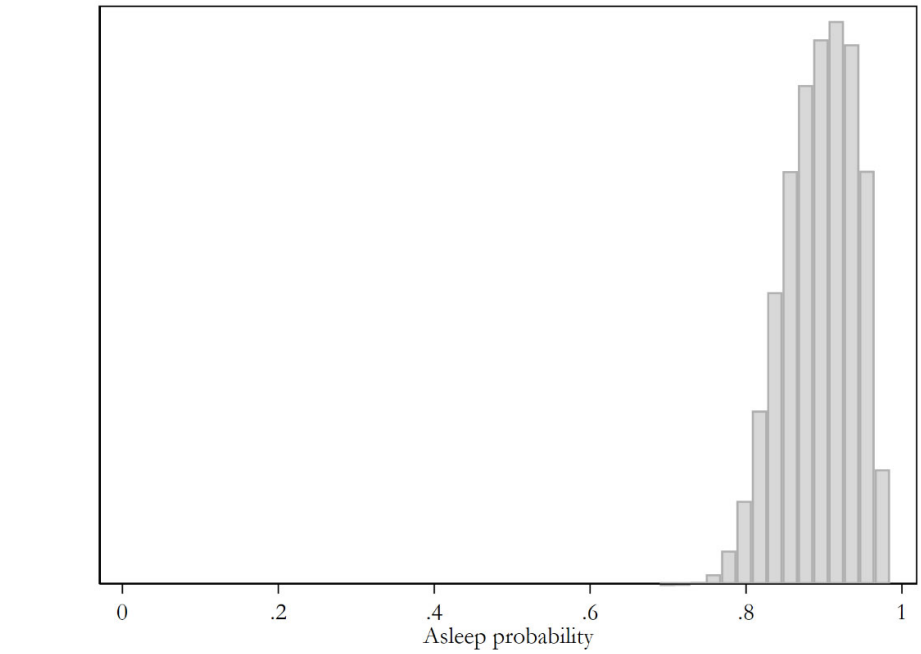


Figure C3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table C1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.



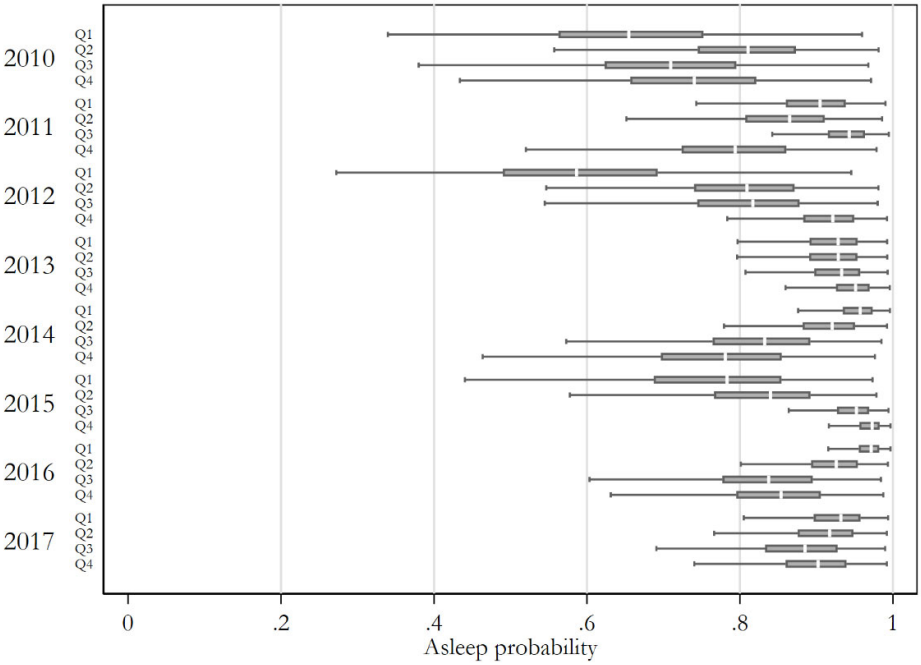
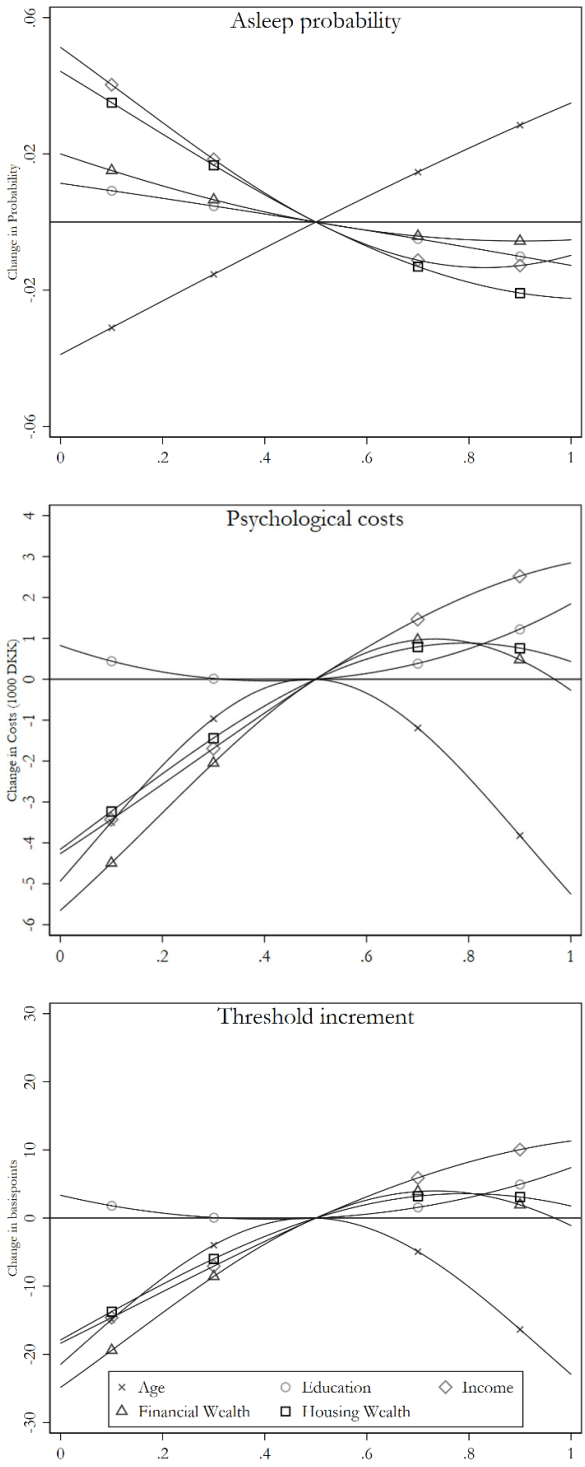


Figure C4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table C1.



Appendix D: Excluding Households that Refinance to ARM

Table D1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix D we exclude households that refinance to an adjustable rate mortgage (ARM). We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column lists the parameters of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives, and the rows show its dependence on the listed demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = exp(φ)) once again as a function of demographic characteristics, and exp(β), which does not depend on demographics, captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	1.202***	2.274***	3.035***
Single male household		-0.107***	0.053***
Single female household		-0.094	-0.070**
Married household		0.146***	-0.078***
Children in family		0.142***	0.089***
Immigrant		-0.118***	0.191***
Financially literate		-0.166***	-0.026
Family financially literate		0.005	-0.089***
Getting married		-0.176***	-0.126***
Having children		-0.077***	-0.073***
Region of Northern Jutland		0.123***	-0.327***
Region of Middle Jutland		0.127***	-0.258***
Region of Southern Denmark		0.107***	-0.141***
Region of Zealand		0.131***	0.104***
Demeaned rank of:			
Age		0.011	0.686***
Length of education		0.040*	-0.283***
Income		0.784***	-0.833***
Financial wealth		0.623***	-0.248***
Housing wealth		0.706***	-0.764***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-1.346***	0.209***
Length of education		0.219***	-0.131***
Income		-0.304***	0.606***
Financial wealth		-0.649***	0.385***
Housing wealth		-0525***	-0.440***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.074	
Log likelihood		-910,793	
Observations		8,394,576	

Figure D1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table D1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

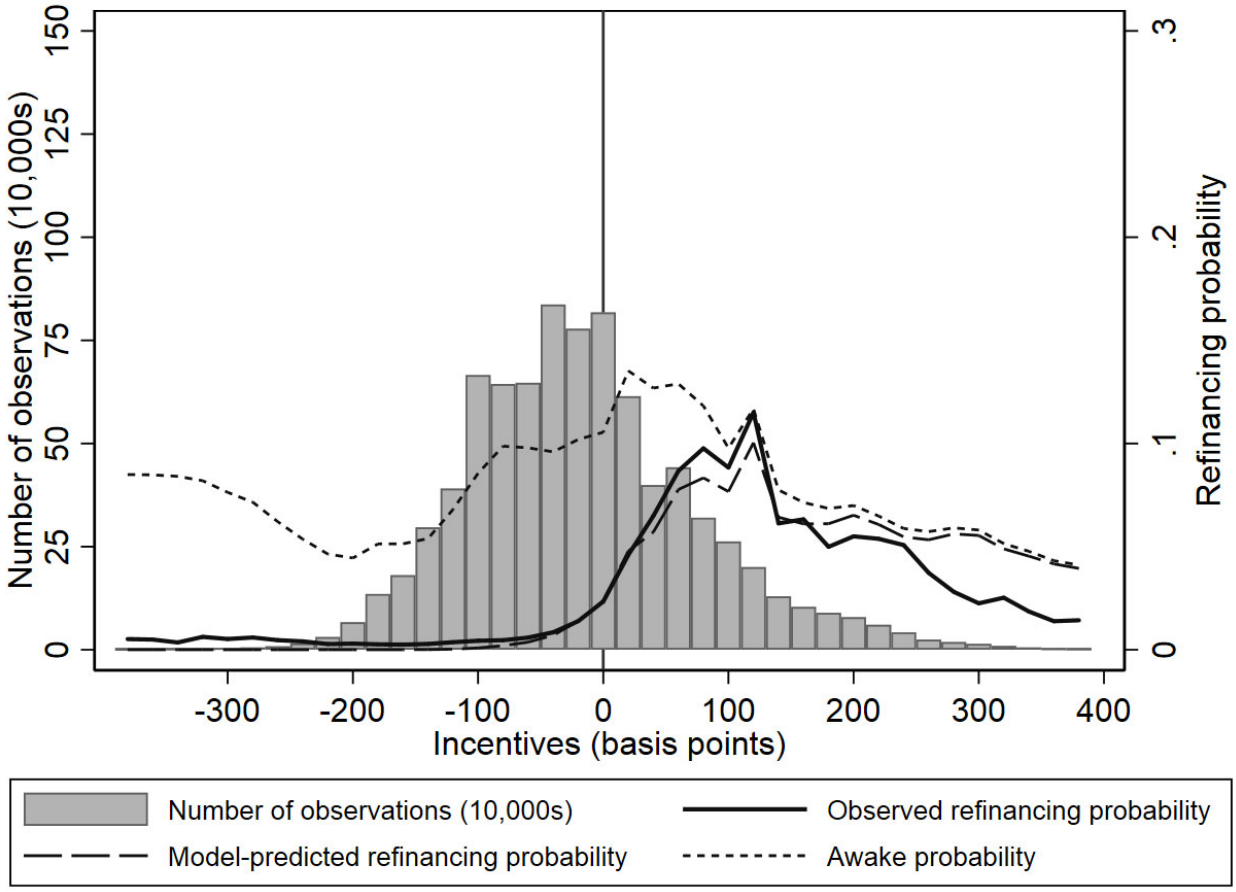


Figure D2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table D1 over the entire sample period. The three plots in the left column show the costs in 1,000 DKK, while the three plots in the right column show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

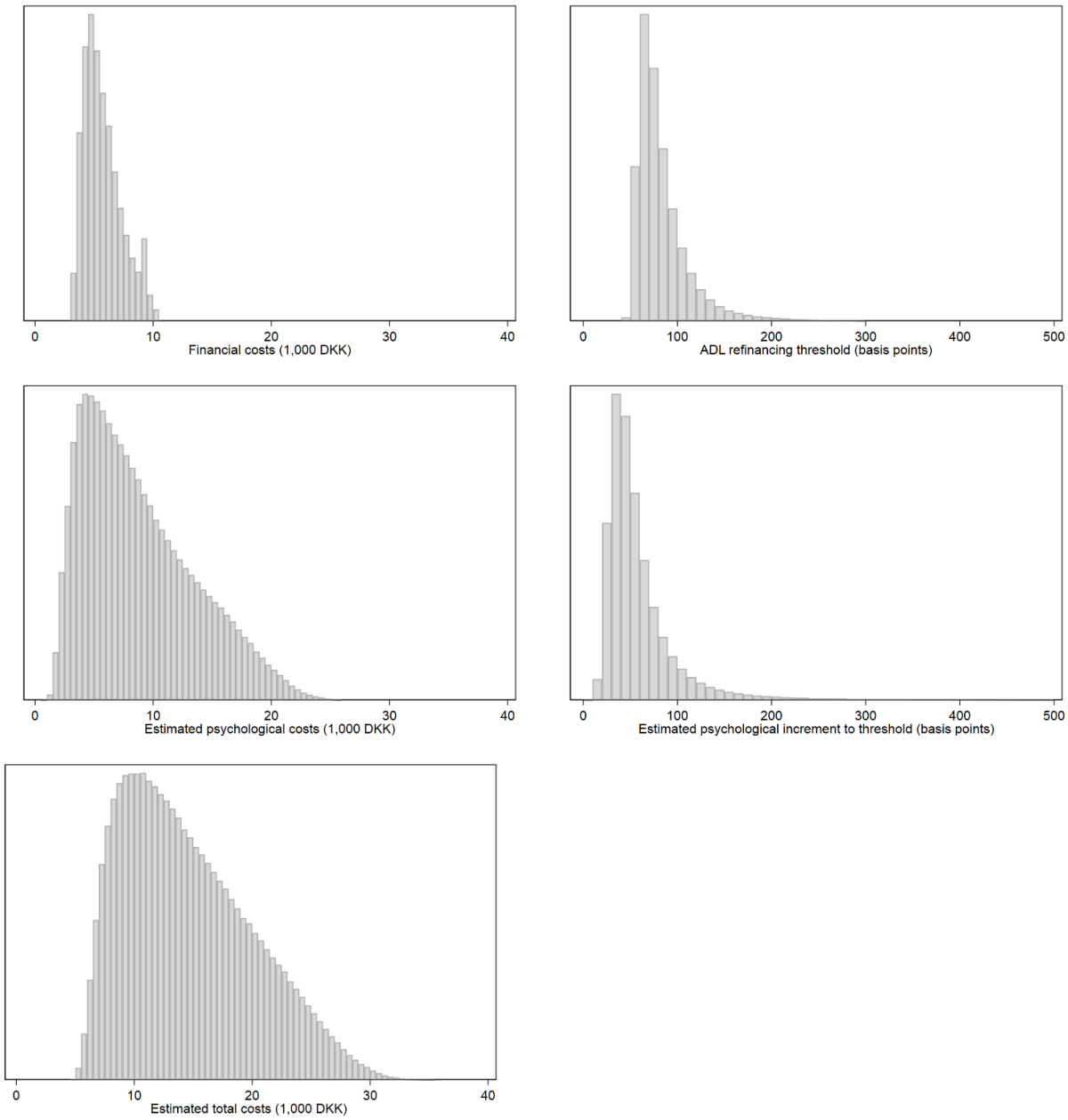
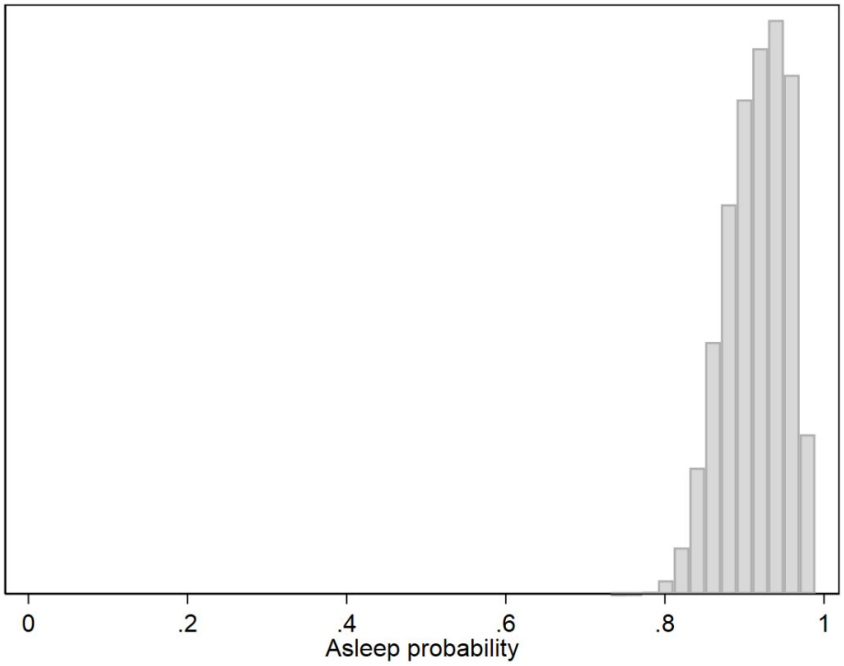


Figure D3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table D1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.



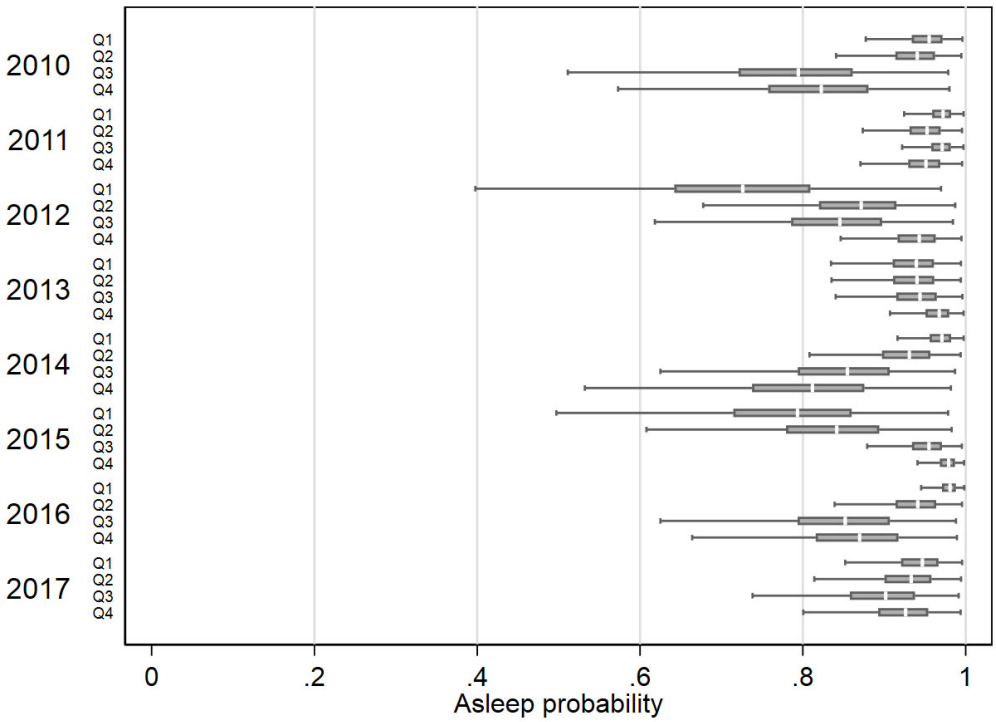
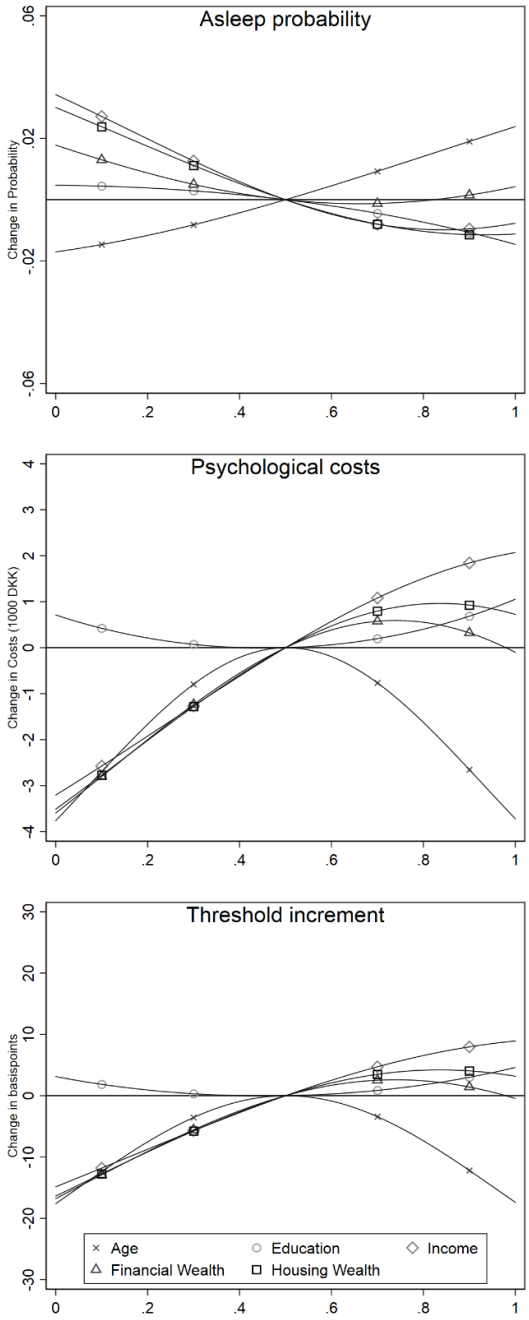


Figure D4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table D1.



Appendix E: Excluding Short and Small Mortgages

Table E1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix E specification we exclude all Mortgages with shorter horizons (<20 years) and all small mortgages (<0.25 M kroner principal). We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = exp(φ)) as a function of demographic characteristics, and exp(β) captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2x^2}$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.921***	2.546***	2.960***
Single male household		-0.138***	0.003
Single female household		-0.079***	-0.141***
Married household		0.162***	-0.072***
Children in family		0.138***	0.088***
Immigrant		-0.178***	0.221***
Financially literate		-0.133***	-0.043***
Family financially literate		0.011	-0.115***
Getting married		-0.178***	-0.098***
Having children		-0.128***	-0.066***
Region of Northern Jutland		0.064***	-0.213***
Region of Middle Jutland		0.034***	-0.154***
Region of Southern Denmark		-0.007	0.062***
Region of Zealand		0.036**	0.199***
Demeaned rank of:			
Age		0.117**	0.648***
Length of education		0.055	-0.237***
Income		0.872***	-0.821***
Financial wealth		0.705***	-0.201***
Housing wealth		0.705***	-0.923***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-1.240***	-0.059
Length of education		0.275***	-0.074
Income		-0.342***	0.544***
Financial wealth		-1.089***	0.199***
Housing wealth		-0.696***	0.381***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.067	
Log likelihood		-1,059,639	
Observations		6,902,171	

Figure E1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table E1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

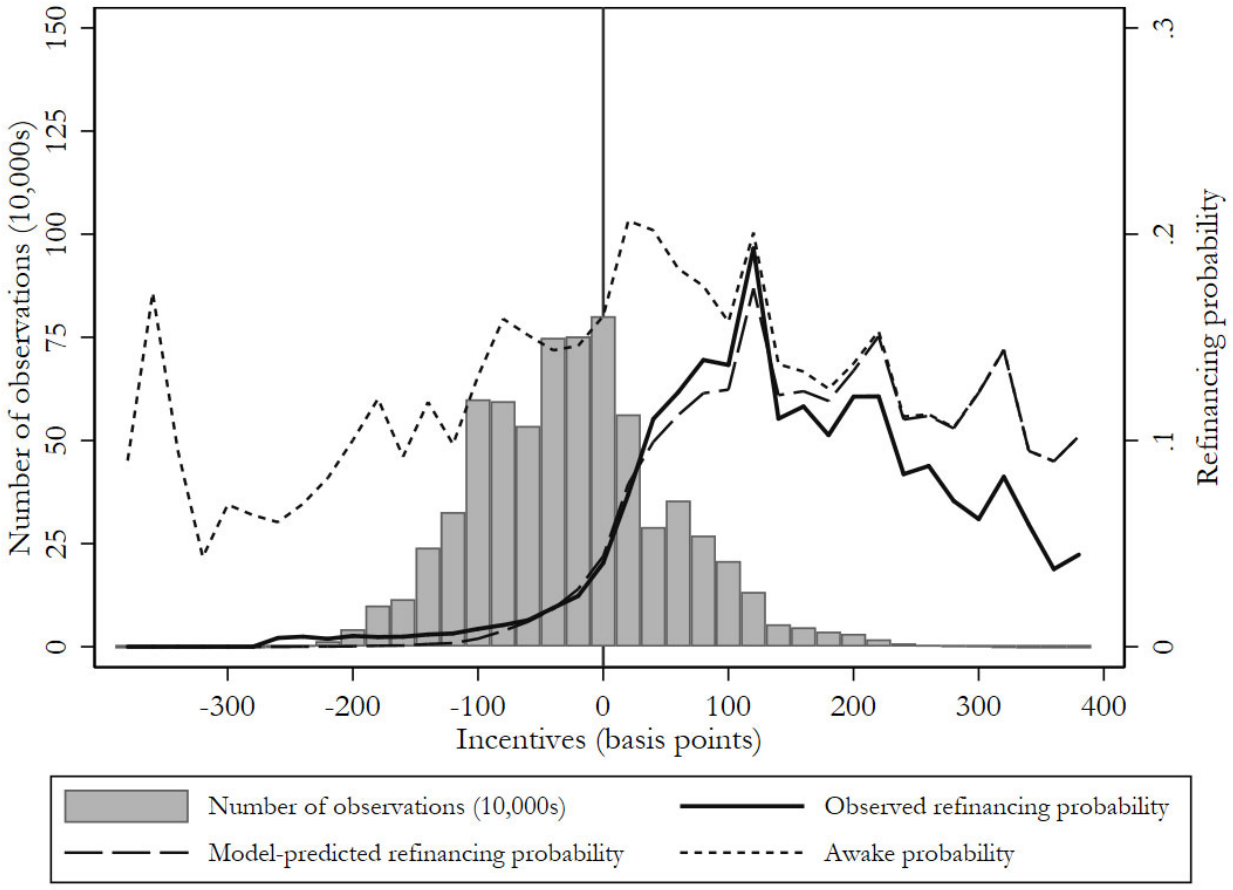


Figure E2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table E1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

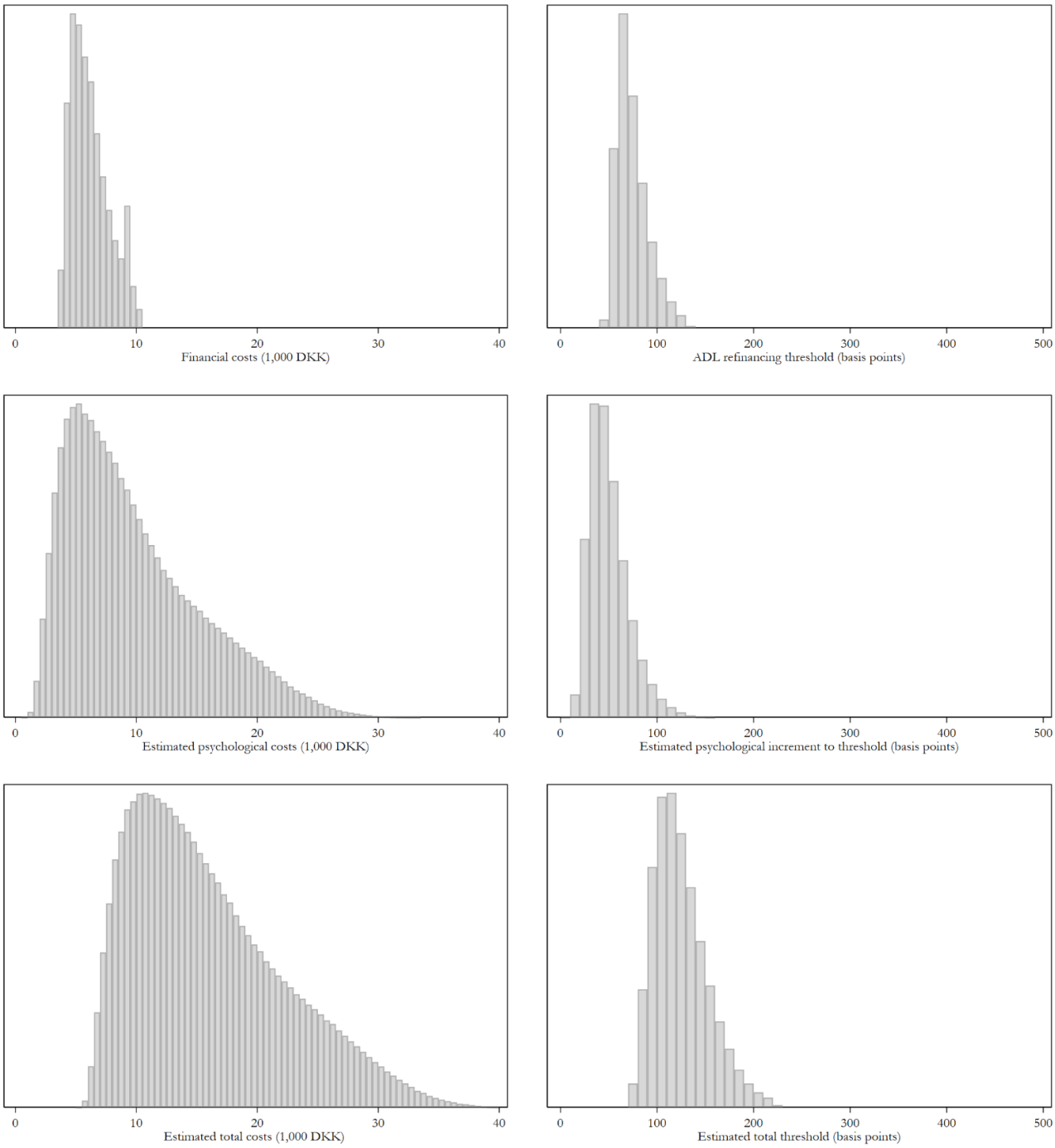
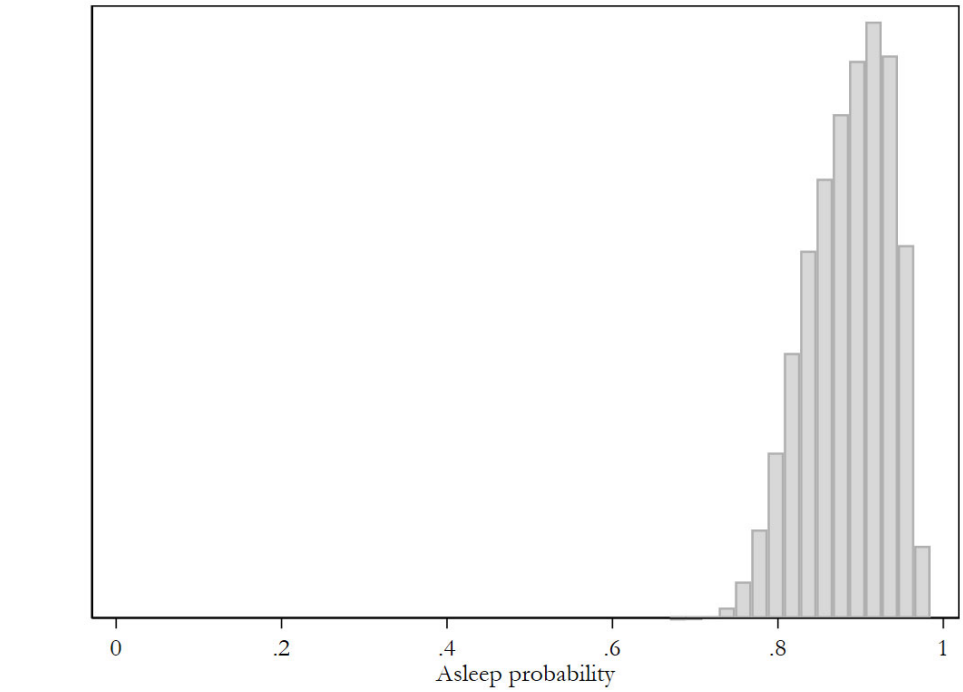


Figure E3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table E1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.



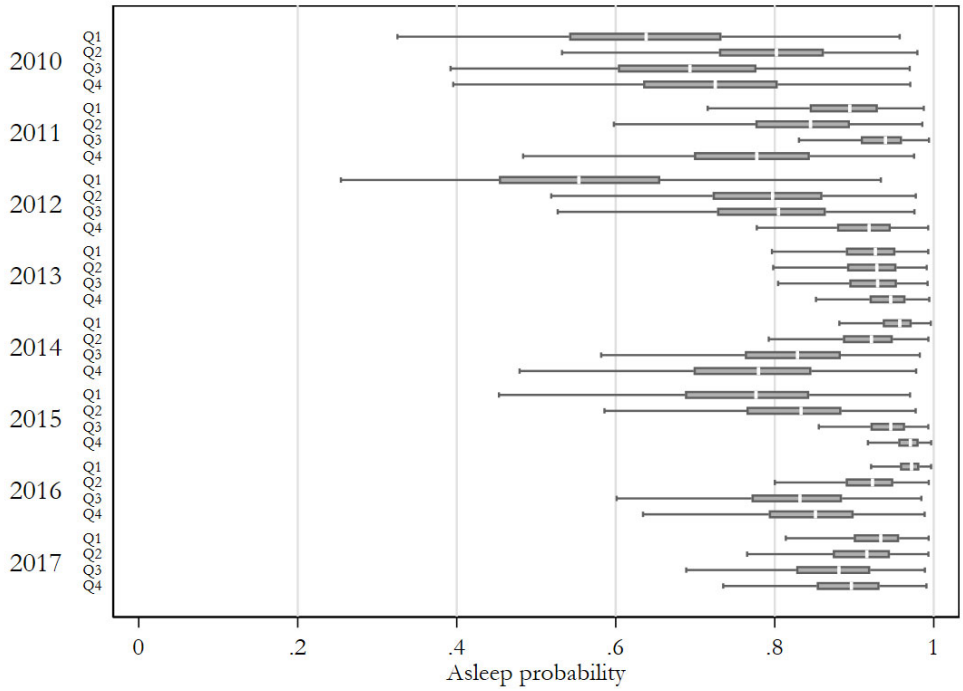
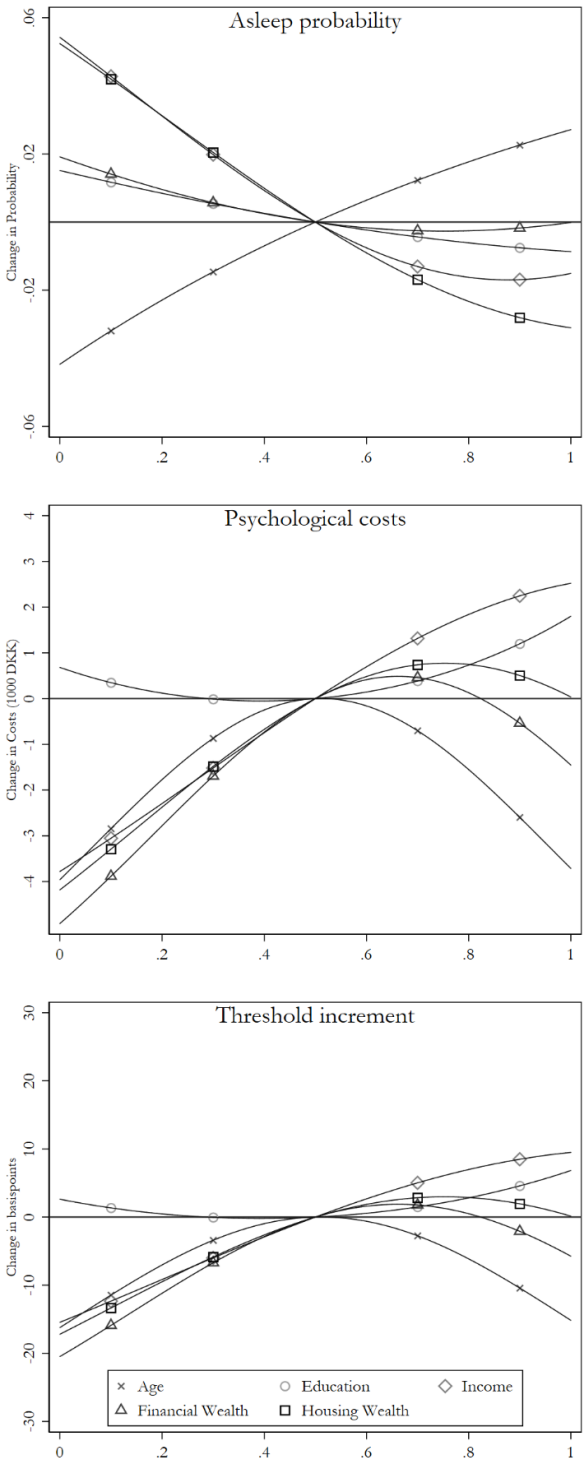


Figure E4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table E1.



Appendix F: ADL threshold levels under alternative assumptions

Figure F1:

This figure plots household-level ADL threshold levels (i.e., without the psychological increment to the threshold level) in basis points for our baseline assumption of interest volatility of 0.0074 basis points and discount rates of 5% against an alternative ADL threshold calculated at interest volatility of 0.0037. The figure plots 1% of the sample.

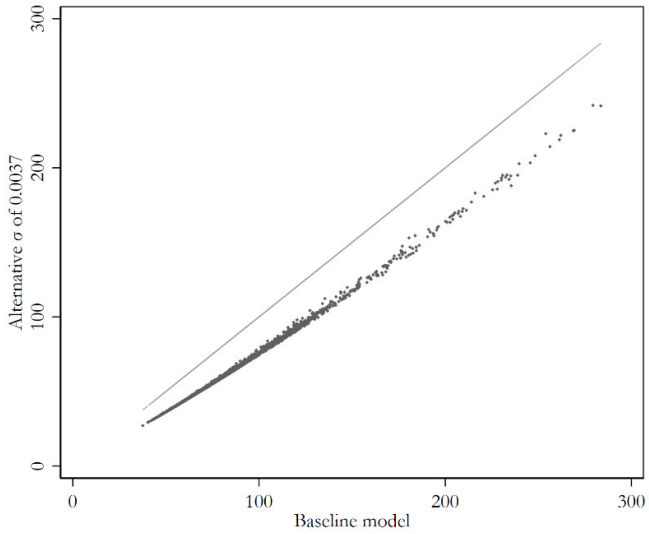
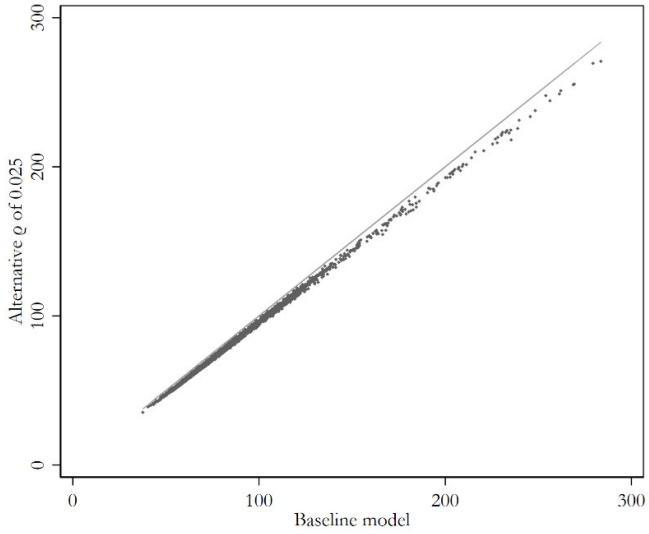


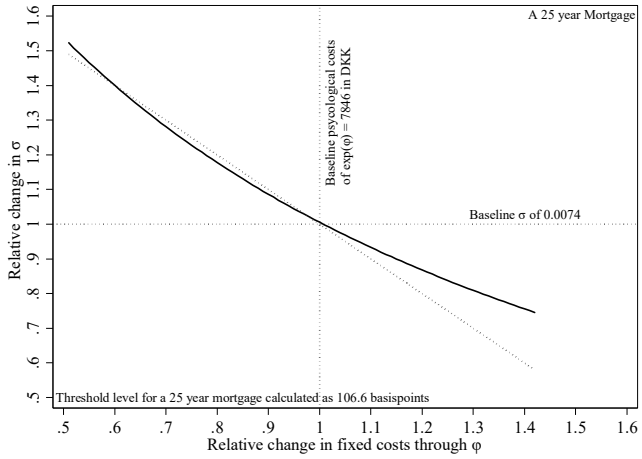
Figure F2:

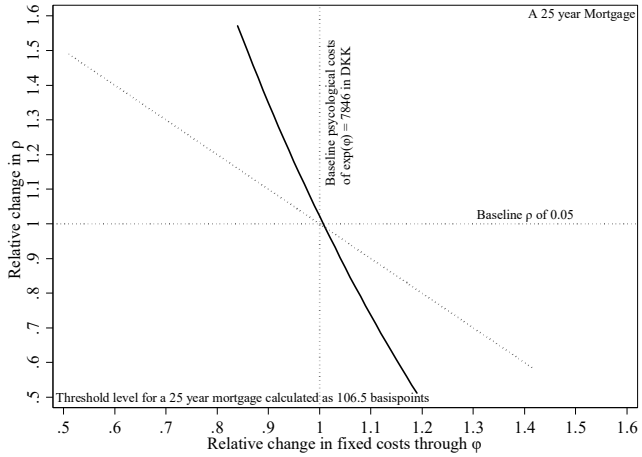
This figure plots household-level estimated ADL threshold levels (i.e., without the psychological increment to the threshold level) in basis points for our baseline assumption of interest volatility of 0.0074 basis points and discount rates of 5% against an alternative ADL threshold calculated at discount rates of 2.5%. The figure plots 1% of the sample.



Appendix F3: Iso Threshold Curve

This figures shows iso-threshold curves for a 25-year to runoff with a 5% coupon rate mortgage. The baseline psychological costs are calculated to be 7846 DKK by setting all other components at the sample medians. In the top figure, we show the relative change in the interest rate variability expectations necessary to compensate for a relative change in psychological costs. In the bottom figure, we show the relative change in patience necessary to compensate for a relative change in the psychological costs.





Appendix G: Assume Lower Interest Rate Volatility

Table G1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix G specification we assume interest rate volatility expectations to be 0.0037, half of our baseline. We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = $\exp(\varphi)$) as a function of demographic characteristics, and $\exp(\beta)$ captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.866***	2.863***	3.260***
Single male household		-0.078***	-0.003
Single female household		-0.080***	-0.117***
Married household		0.134***	-0.053***
Children in family		0.152***	0.077***
Immigrant		-0.108***	0.158***
Financially literate		-0.138***	-0.024
Family financially literate		-0.007	-0.084***
Getting married		-0.224***	-0.072***
Having children		-0.122***	-0.047***
Region of Northern Jutland		0.106***	-0.265***
Region of Middle Jutland		0.079***	-0.203***
Region of Southern Denmark		0.022	0.092***
Region of Zealand		0.074**	0.135***
Demeaned rank of:			
Age		0.048	0.706***
Length of education		0.092***	-0.232***
Income		0.739***	-0.727***
Financial wealth		0.761***	-0.187***
Housing wealth		0.625***	-0.802***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-1.176***	-0.048
Length of education		0.261***	-0.001
Income		-0.299***	0.579***
Financial wealth		-0.841***	0.125***
Housing wealth		-0.546***	0.359***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.069	
Log likelihood		-1,325,572	
Observations		9,351,182	

Figure G1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table G1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

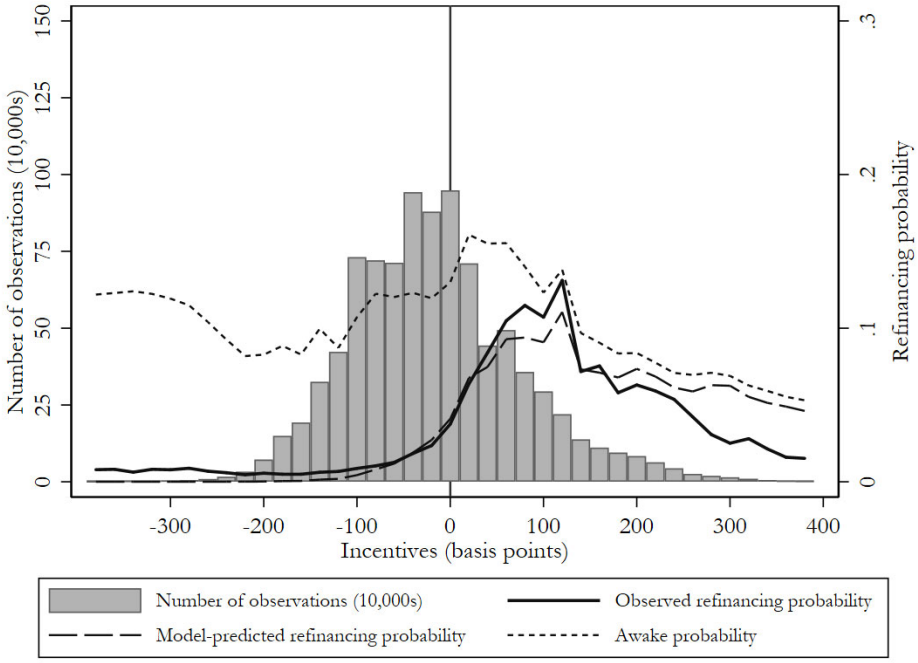


Figure G2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table G1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

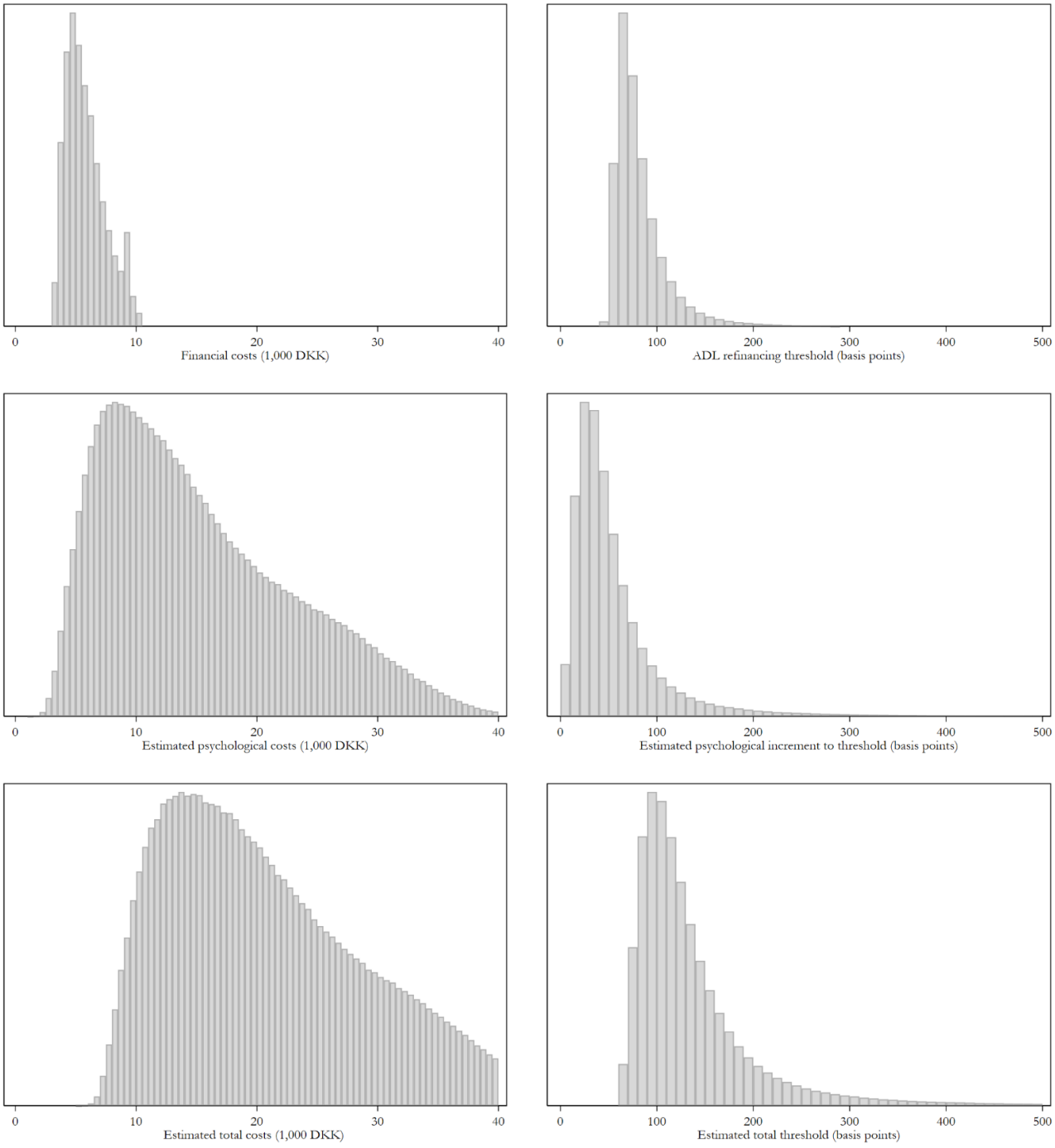
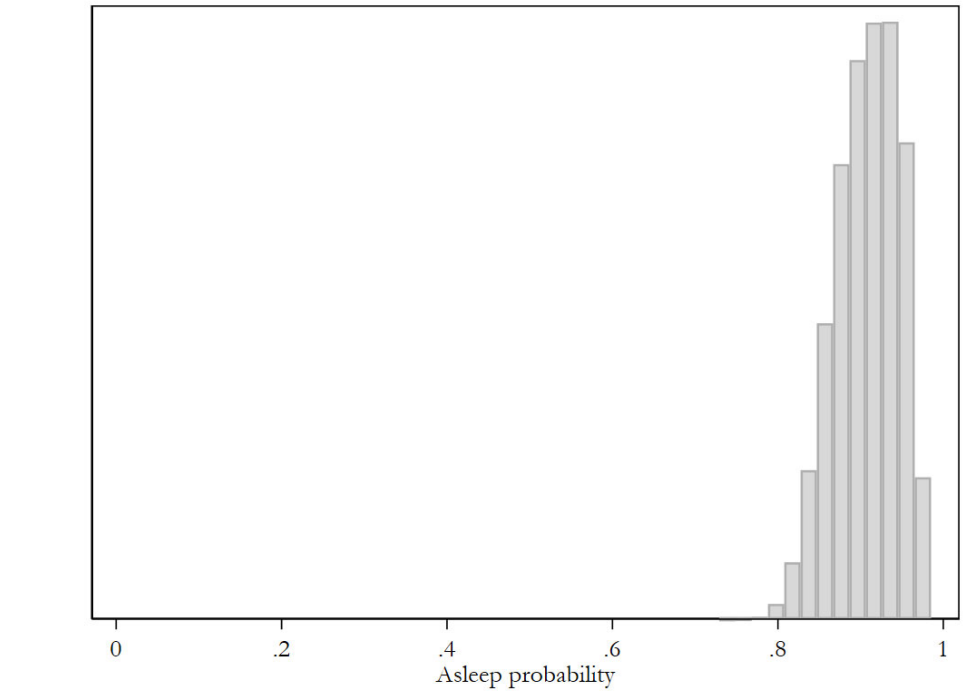


Figure G3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table G1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.



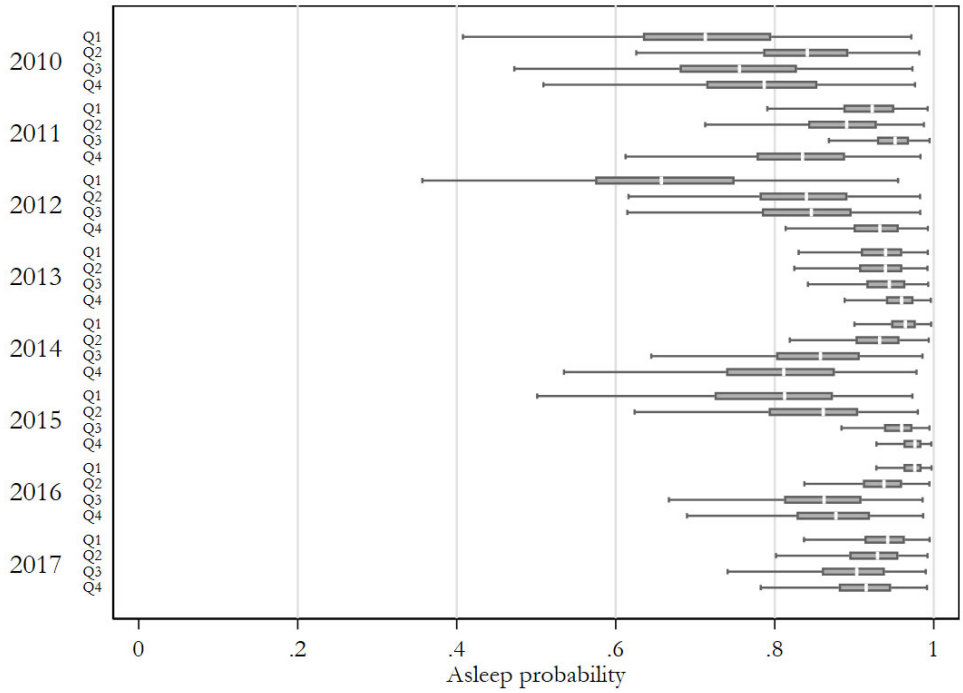
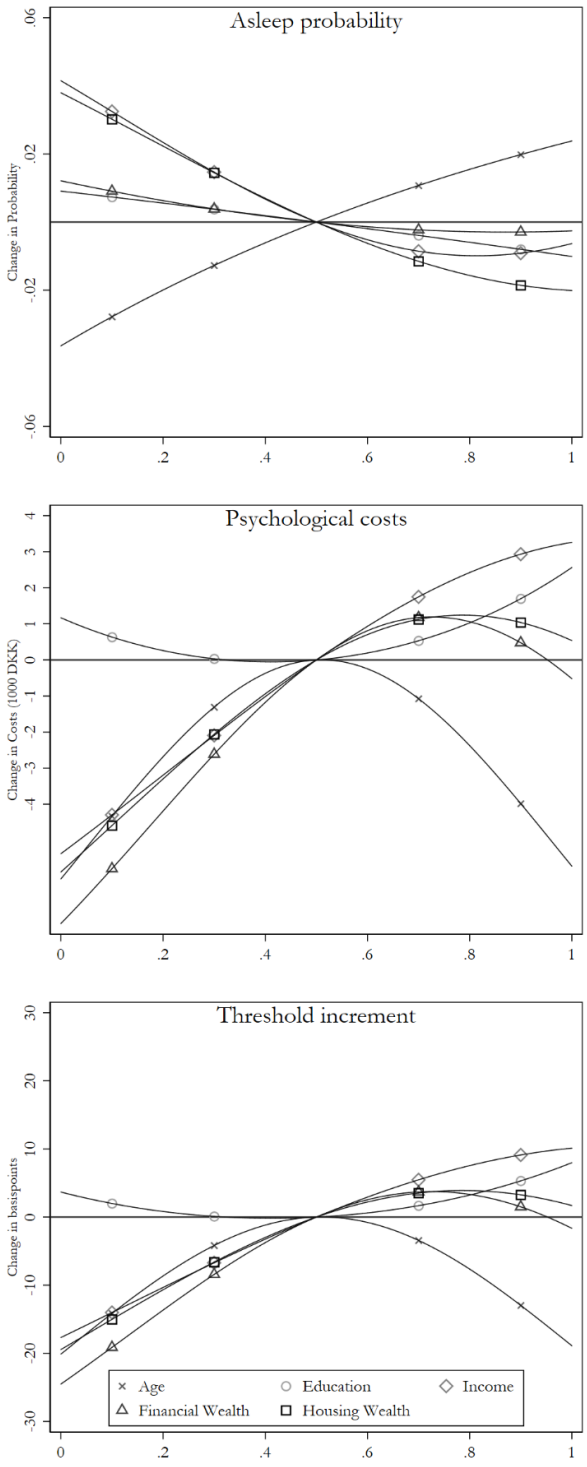


Figure G4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table G1.



Appendix H: Assume Lower Discount Rates

Table H1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix H specification, we assume discount rates to be 0.025, half of our baseline. We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = $\exp(\varphi)$) as a function of demographic characteristics, and $\exp(\beta)$ captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.821***	2.668***	3.260***
Single male household		-0.092***	0.005
Single female household		-0.107***	-0.110***
Married household		0.119***	-0.039***
Children in family		0.129***	0.099***
Immigrant		-0.122***	0.161***
Financially literate		-0.157***	-0.019
Family financially literate		-0.003	-0.092***
Getting married		-0.247***	-0.069***
Having children		-0.119***	-0.084***
Region of Northern Jutland		0.117***	-0.275***
Region of Middle Jutland		0.086***	-0.211***
Region of Southern Denmark		0.029*	0.097***
Region of Zealand		0.071**	0.143***
Demeaned rank of:			
Age		-0.010	0.774***
Length of education		0.103***	-0.249***
Income		0.814***	-0.761***
Financial wealth		0.898***	-0.242***
Housing wealth		0.633***	-0.817***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-1.322***	-0.027
Length of education		0.265***	-0.002
Income		-0.389***	0.613***
Financial wealth		-0.926***	0.139***
Housing wealth		-0.579***	0.377***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.070	
Log likelihood		-1,323706	
Observations		9,351,182	

Figure H1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table H1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

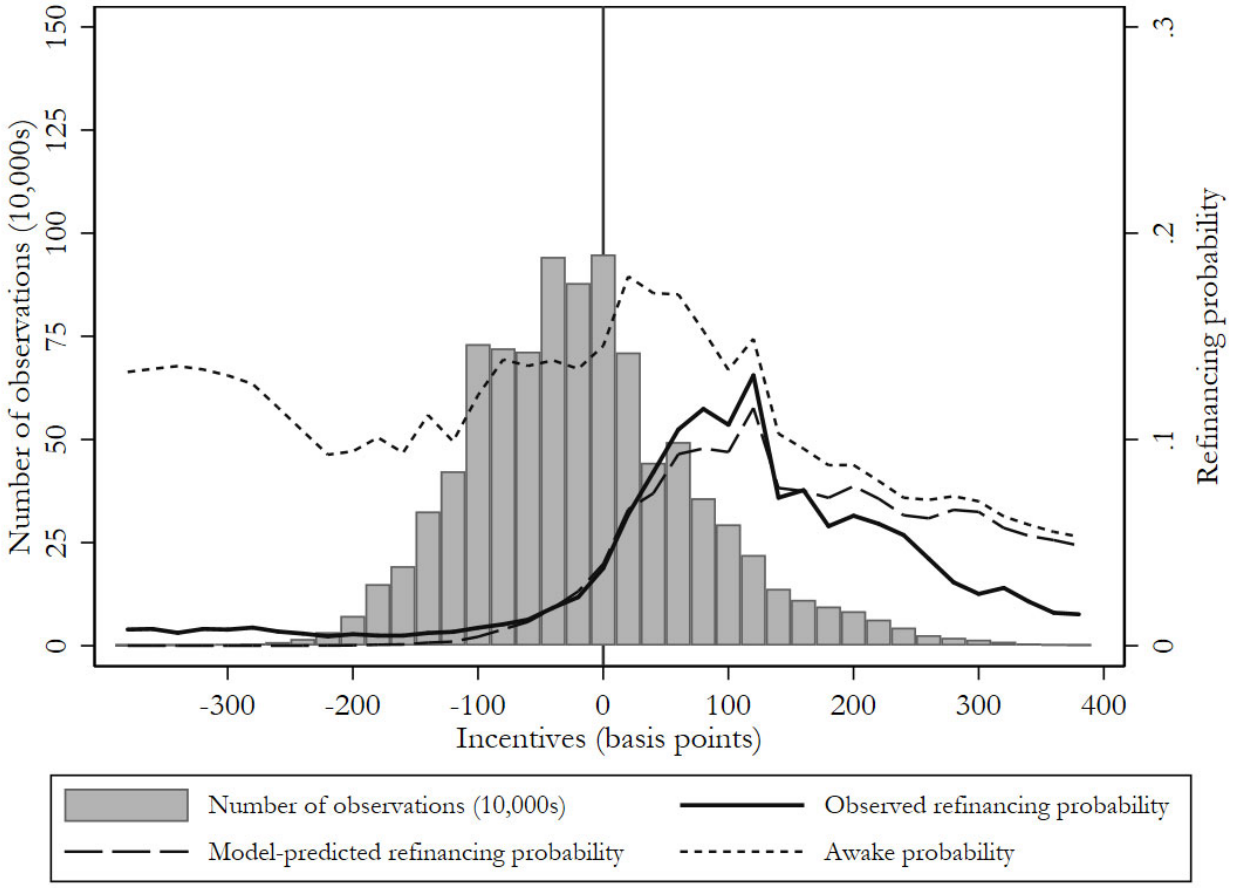


Figure H2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table H1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

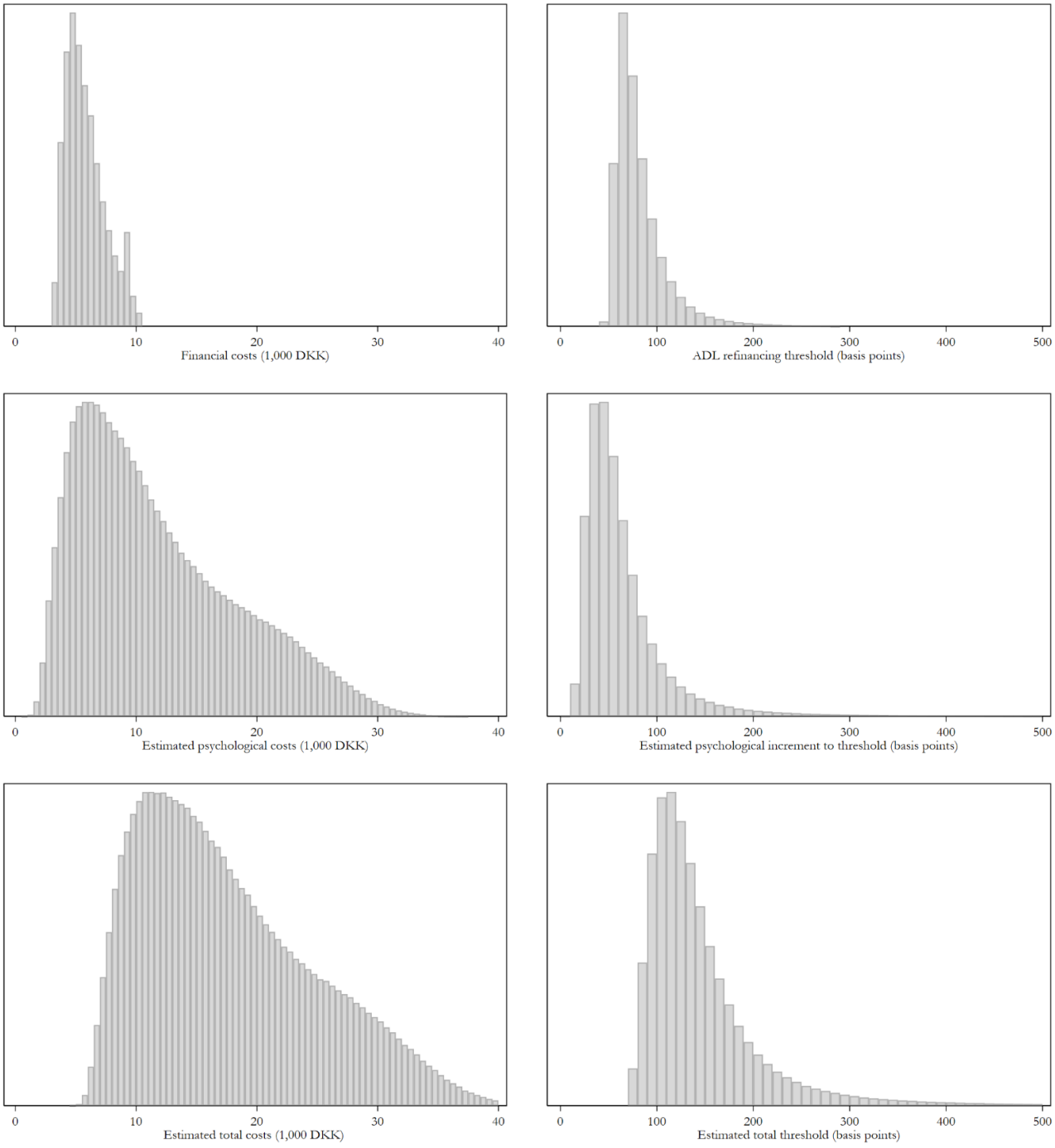
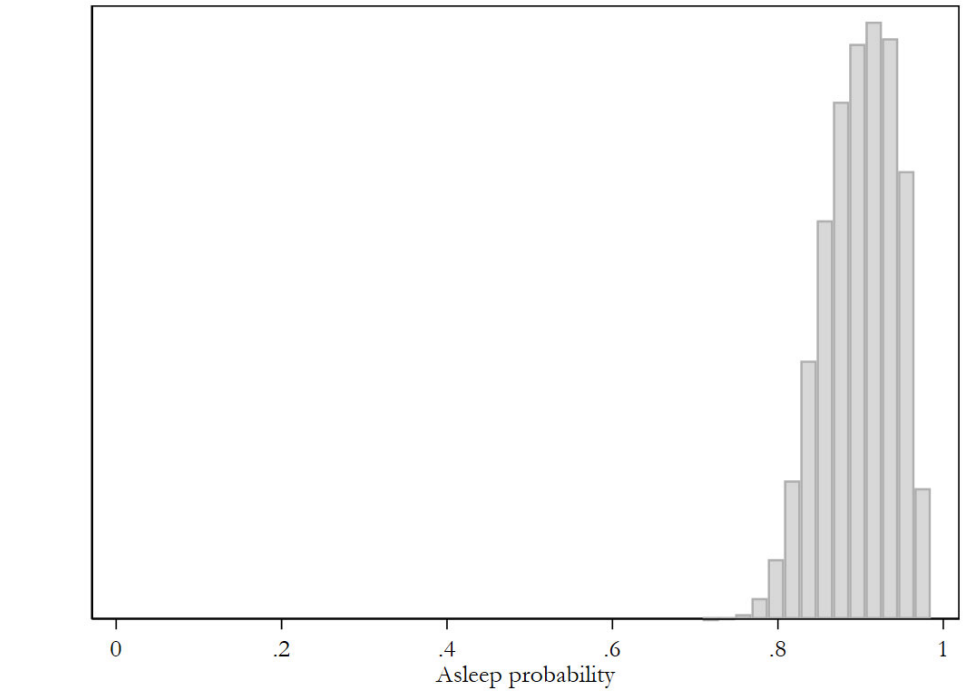


Figure H3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table H1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.



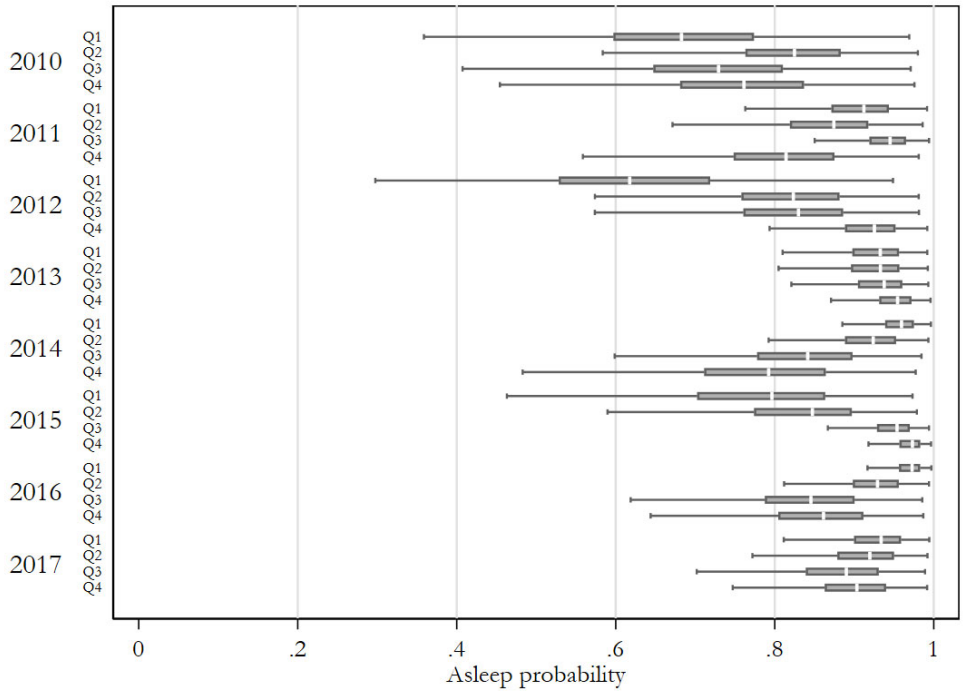
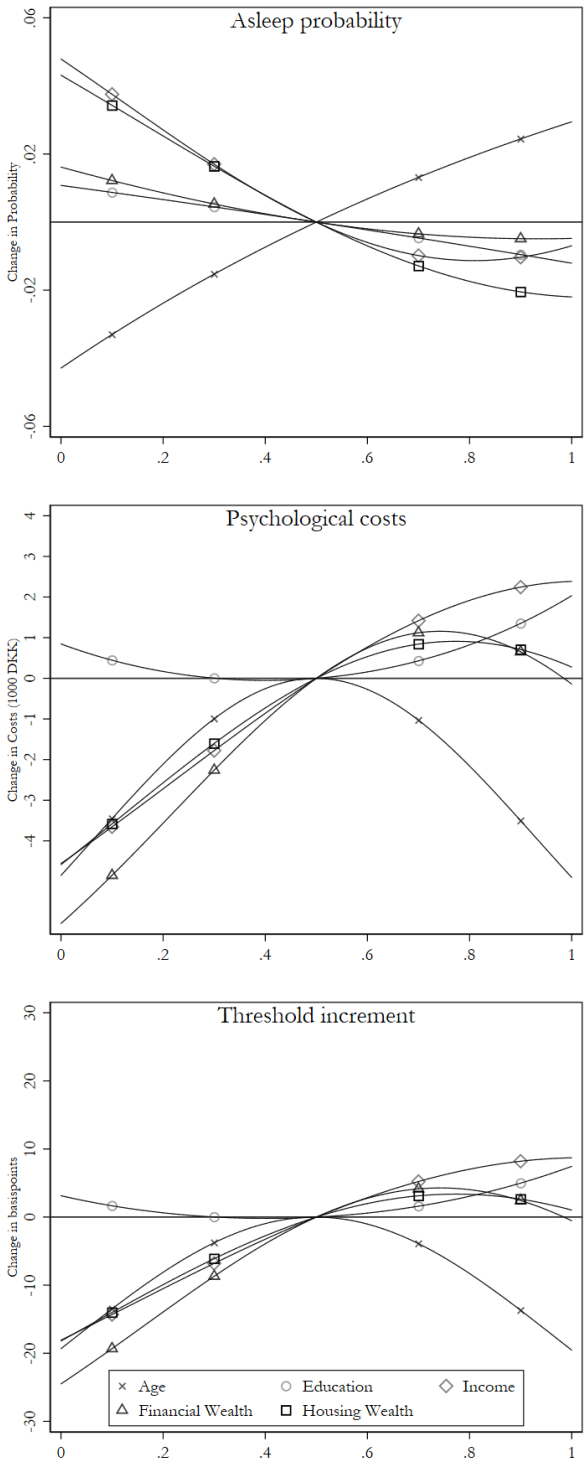


Figure H4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table H1.



Appendix I: Using a Fixed Mortgage Termination Probability

Table I1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix I specification, we assume a fixed mortgage termination probability of 10% per annum. We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2014. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = $\exp(\varphi)$) as a function of demographic characteristics, and $\exp(\beta)$ captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.798^{***}	2.556^{***}	3.260^{***}
Single male household		0.018	0.020
Single female household		-0.030^{***}	-0.116^{***}
Married household		0.058^{***}	-0.058^{***}
Children in family		-0.049^{***}	0.096^{***}
Immigrant		0.012^{***}	0.161^{***}
Financially literate		-0.144^{***}	-0.022
Family financially literate		0.005	-0.095^{***}
Getting married		-0.156^{***}	-0.085^{***}
Having children		-0.007	-0.093^{***}
Region of Northern Jutland		0.016^{***}	-0.291^{***}
Region of Middle Jutland		0.006^{***}	-0.217^{***}
Region of Southern Denmark		-0.063^{***}	0.098^{***}
Region of Zealand		-0.005^{**}	0.146^{***}
Demeaned rank of:			
Age		-0.762^{***}	0.814^{***}
Length of education		0.162^{***}	-0.280^{***}
Income		0.604^{***}	-0.812^{***}
Financial wealth		0.755^{***}	-0.273^{***}
Housing wealth		0.518^{***}	-0.831^{***}
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-0.584^{***}	0.000
Length of education		0.344^{***}	-0.070
Income		-0.284^{***}	0.627^{***}
Financial wealth		-0.423^{***}	0.249^{***}
Housing wealth		-0.087^{***}	0.428^{***}
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.066	
Log likelihood		-1,319115	
Observations		9,351,182	

Figure I1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table I1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

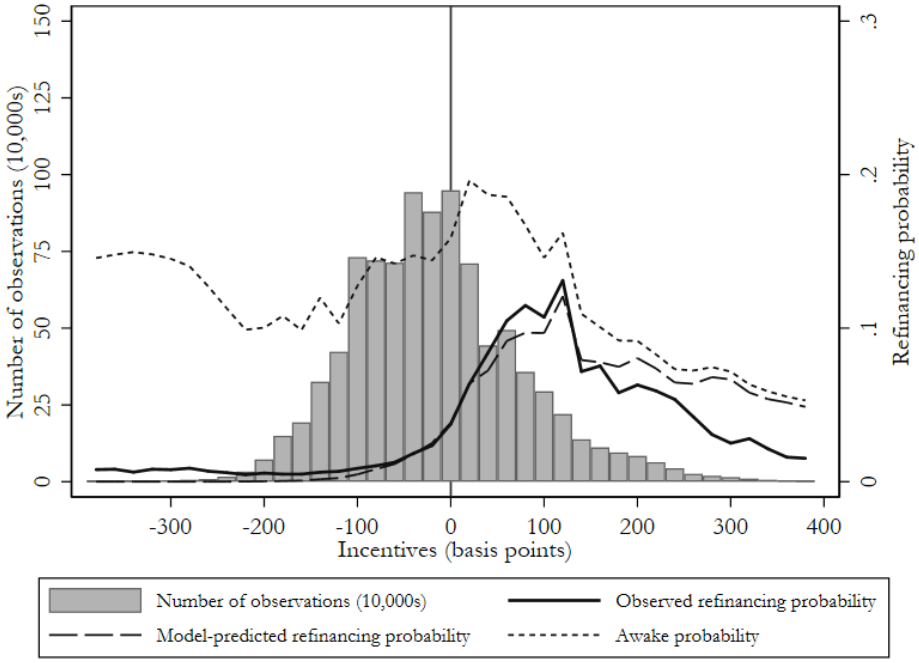


Figure I2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table I1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

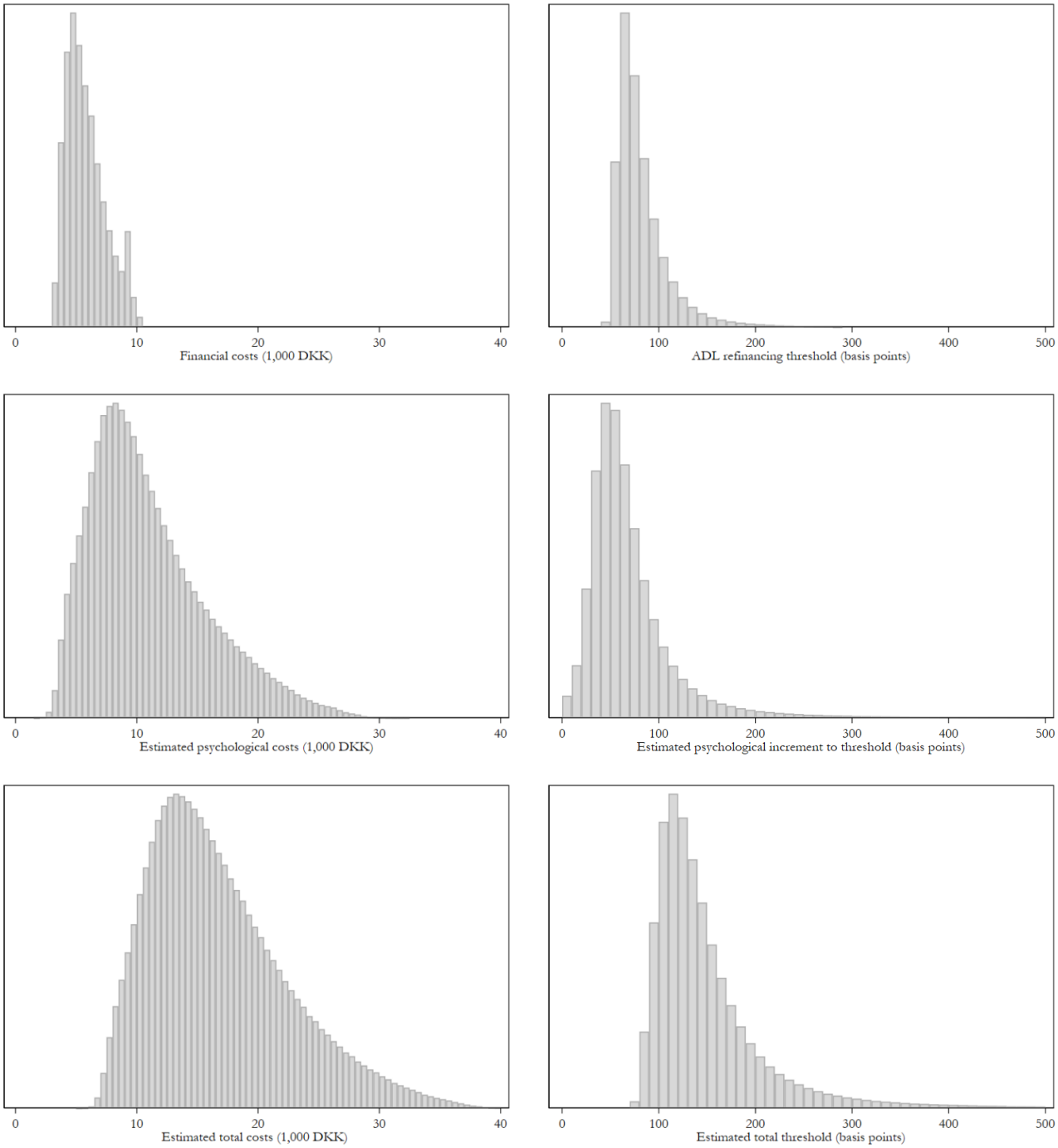


Figure I3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table I1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.

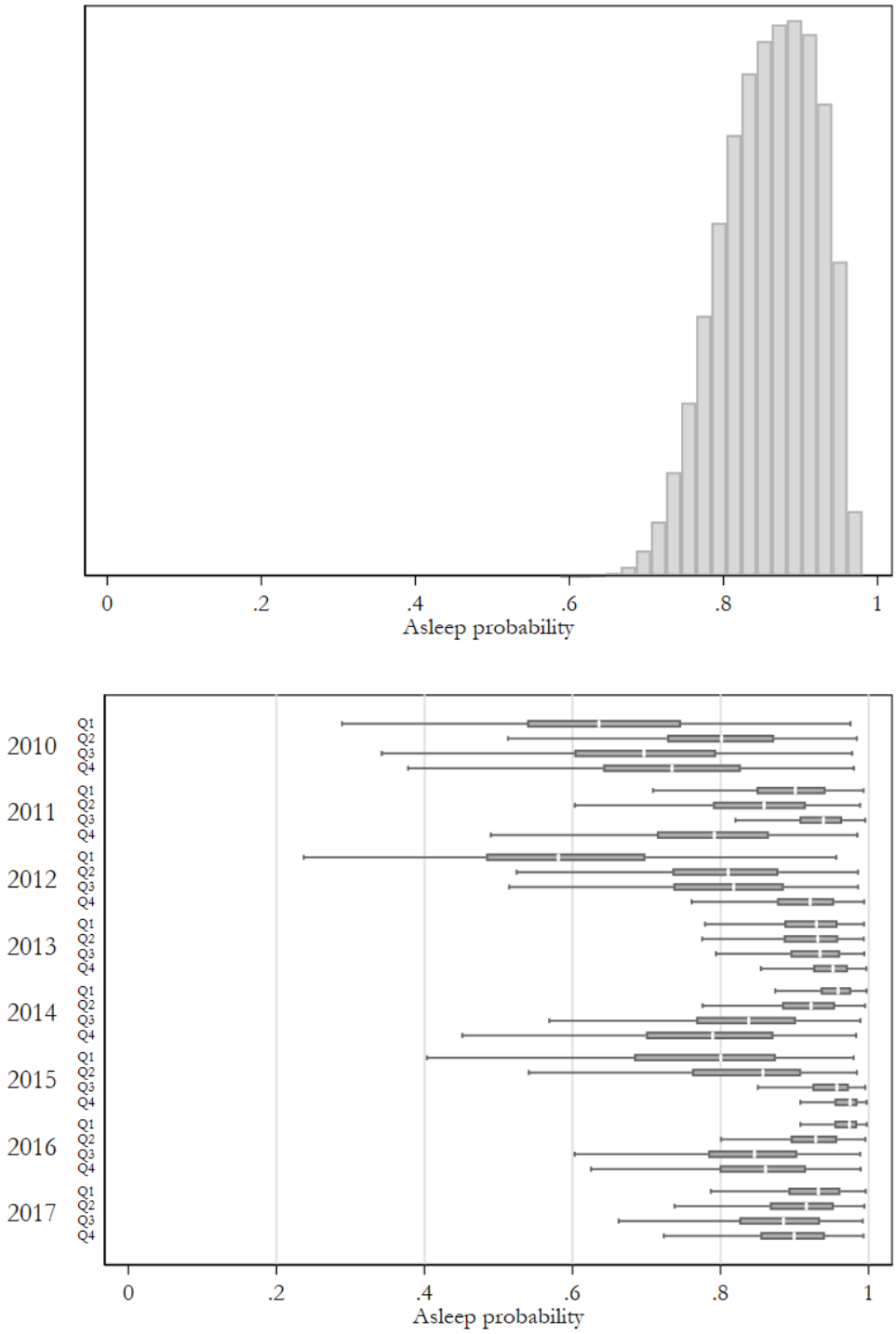
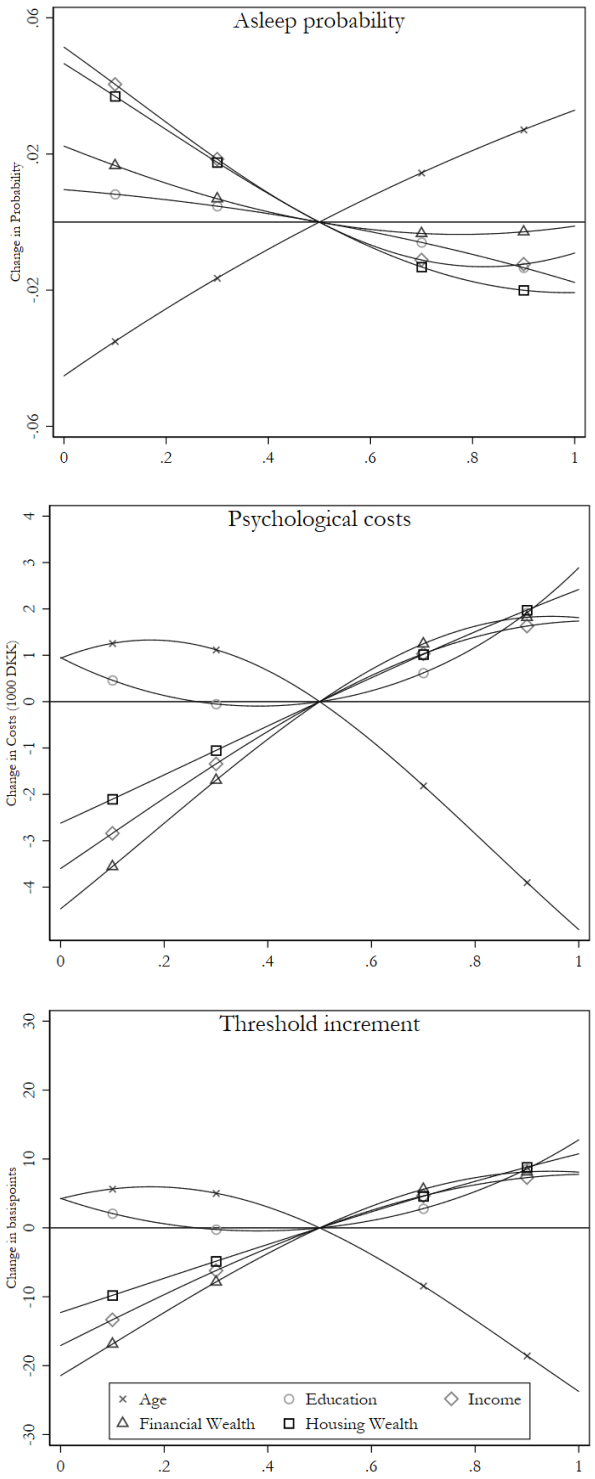


Figure I4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table I1.



Appendix J: Allow Heterogeneity in Responsiveness to Incentives

Table J1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix J specification we allow for heterogeneity in the responsiveness (exp(z'β)) to incentives. We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2014. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = exp(φ)) as a function of demographic characteristics, and exp(β) captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where f(x) = $\sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.792***	2.524***	3.260***
Single male household	-0.036*	-0.018	-0.032
Single female household	0.015	-0.108**	-0.110***
Married household	0.079***	0.014***	-0.007***
Children in family	0.036***	0.108***	0.095***
Immigrant	-0.045***	0.046*	0.144***
Financially literate	-0.011	-0.169***	-0.012
Family financially literate	0.024**	-0.038**	-0.076***
Getting married	0.041	-0.300***	-0.045
Having children	-0.065***	-0.051	-0.104***
Region of Northern Jutland	0.103***	0.019	-0.257***
Region of Middle Jutland	0.094***	-0.005	-0.191***
Region of Southern Denmark	0.030**	0.007	-0.099***
Region of Zealand	0.042***	0.021	0.150***
Demeaned rank of:			
Age	0.011	-0.006	0.742***
Length of education	0.190***	-0.118***	-0.161***
Income	0.174***	0.575***	-0.690***
Financial wealth	0.024*	0.870***	-0.270***
Housing wealth	0.309***	0.210***	-0.646***
Non-linear transformation f(x), x is the demeaned rank of:			
Age	-0.142***	-0.989***	-0.131***
Length of education	0.261***	-0.014***	-0.087
Income	-0.169***	-0.063	0.506***
Financial wealth	-0.519***	-0.273***	-0.074***
Housing wealth	-0.371***	-0.018	0.148***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.064	
Log likelihood		-1,32,688	
Observations		9,351,182	

Figure J1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table J1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

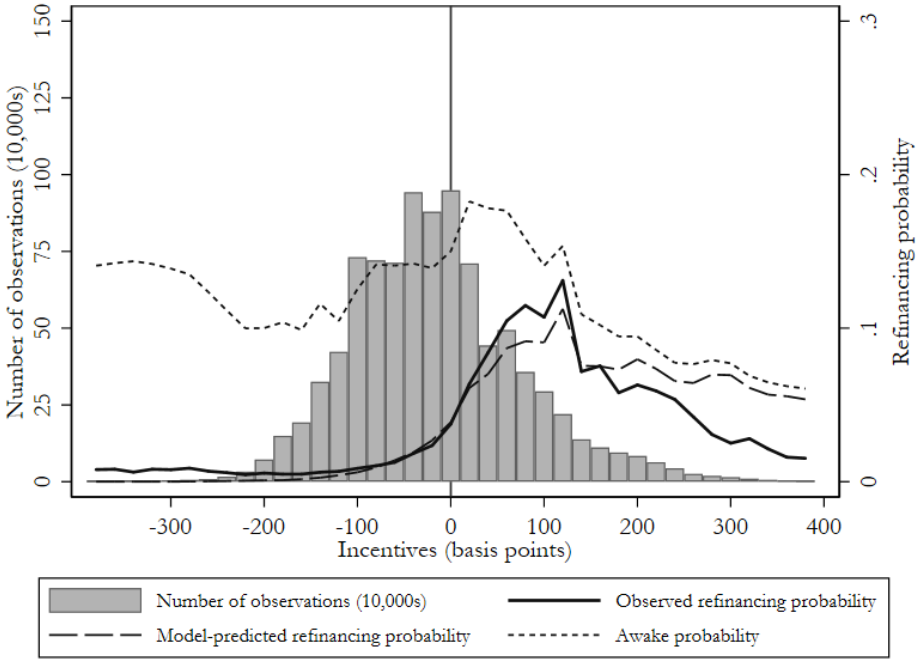


Figure J2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table J1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the ADL (2013) function. Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

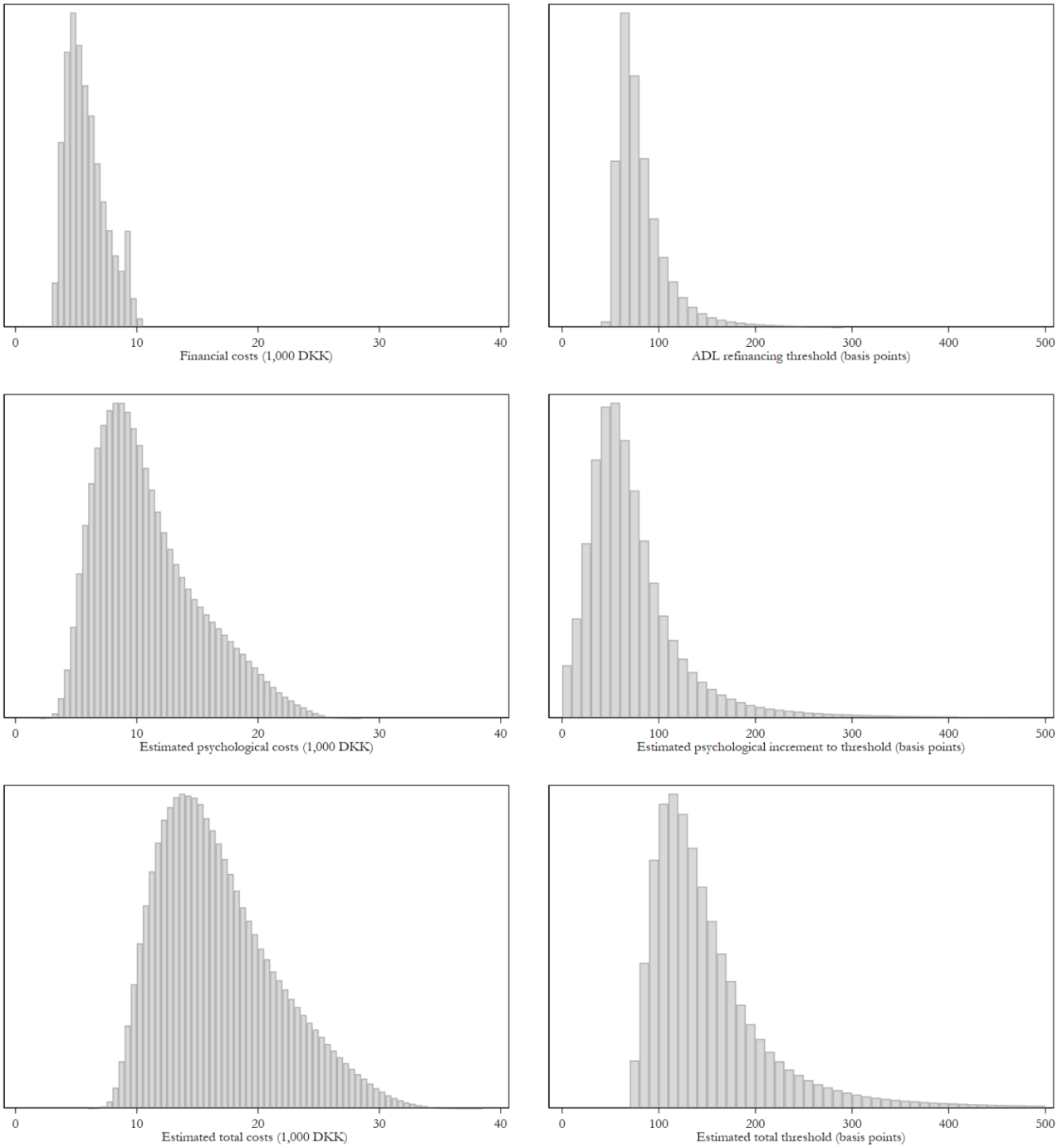


Figure J3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table J1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.

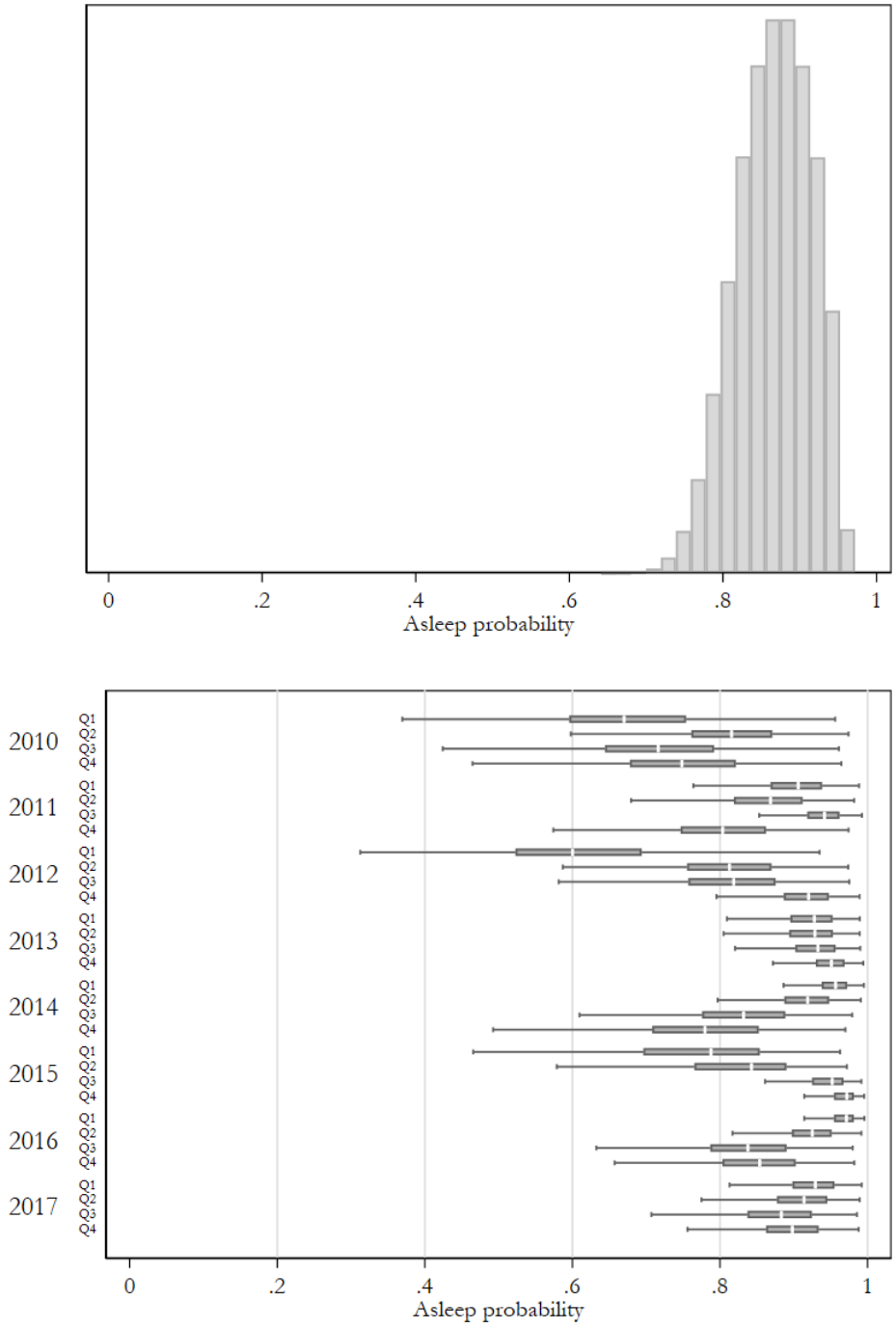
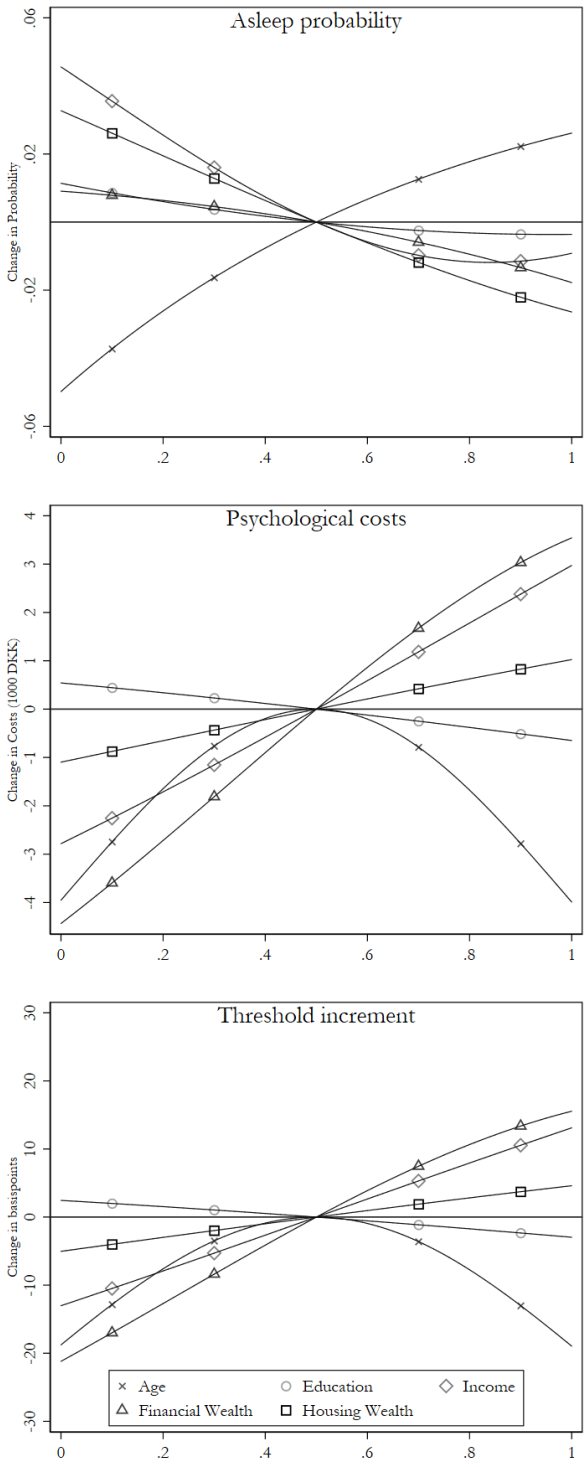


Figure J4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table J1.



Appendix K: Relationship between ADL threshold and CL thresholds

Chen and Ling (1989) (henceforth CL) use an alternative set of assumptions and compute a threshold for optimal mortgage refinancing. Their approach differs from the Agarwal, Driscoll, and Laibson (2013) (henceforth ADL) approach in a number of different ways. The principal differences between the two approaches are:

Maturity and mortgage termination.

1. In CL, the mortgage is modelled as having a finite maturity. All mortgages in their setup start out as being of 30 year maturity, but they also need to incorporate the fact that mortgages often terminate on account of household moves, divorce, death, or other exogenous events. To include this feature, they specify a deterministic future date at which the mortgage terminates, in order to match the expected holding period of these mortgages from a stochastic model. This deterministic future date determines what they refer to as the "expected holding period" or *EHP*, which varies across mortgages. Thus, mortgages are modelled as being of a fixed shorter maturity, which in their paper is set as *EHP=8* years in the baseline calculations.
2. In ADL, the mortgage is modelled as infinite maturity. They model the exogenous date of termination (for the same reasons as above) as exponentially distributed, with a hazard rate λ_t of instantaneous termination conditional on survival to date *t*.

Interest rate process.

1. In CL, the short-term interest rate follows a Geometric Brownian Motion (GBM). They assume that the local expectations hypothesis (LEH) holds, and derive the 30-year mortgage interest rate under this assumption. In particular, the stochastic short-term nominal rate for each $0 \leq t < T, dt = \frac{1}{N}$ follows,

$$r^n_{t+dt} = r^n_t \times \epsilon, \text{ with } \epsilon = \begin{cases} \exp\left(\frac{d}{N} + \frac{\sigma}{N}\right) \\ exp\left(\frac{d}{N} - \frac{\sigma}{N}\right) \end{cases}$$

Denoting the current time period as 0, and the current short-term rate as r^n_0, in our empirical application, we find the volatility σ and drift *d* that best match the average rate and volatility of annual changes of the 30-year Danish mortgage bond rate ($T = 30, \bar{y}^T_o = 0.045$ and $\bar{\sigma}_T = 0.0074$):

$$\bar{y}^T_o = -\frac{1}{T} log B_0(T) \quad (1)$$

$$\bar{\sigma}_T = \sigma(y^{T+1}_1 - \bar{y}^T_o) \quad (2)$$

For each time step, the 30-year zero-coupon bond satisfies the LEH:

$$\begin{cases} B_t(T) = \frac{1}{(1+r^n_t dt)} E[B_{t+dt}(T)], 0 \leq t < T, dt = \frac{1}{N} \\ B_t(T) = 1 \end{cases} \quad (LEH)$$

In addition to equations (1) and (2), we also assume that the short-term rate has no drift, i.e.,

$$\mathbf{E}[r^n_{t+dt}] = r^n_t \; \forall t$$

which uniquely defines the drift parameter d. This then allows us to solve for the short-rate and its volatility, which we then use in our simulations to compute thresholds.

2. In contrast, ADL model the long-term fixed rate directly, which is assumed to follow an Arithmetic Brownian Motion (ABM).
3. Refinancing opportunities.
   (a) In CL, there is a one-time option to refinance, and their approach (and optimal refinancing threshold) excludes the possibility of subsequent refinancings.
   (b) In ADL, the calculations (and optimal refinancing threshold) take into account the possibility of subsequent refinancings.

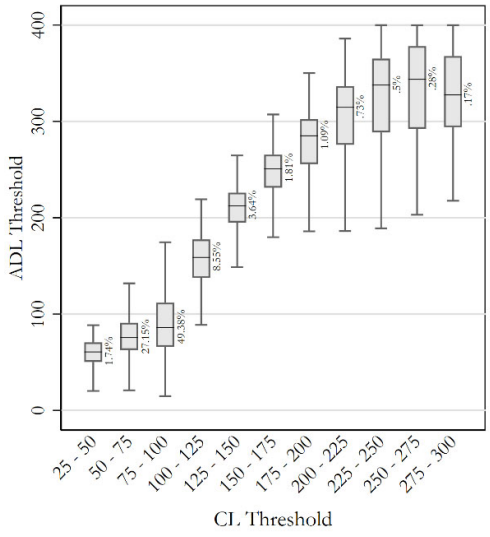
The ADL formula is a closed-form solution for the optimal refinancing threshold, given the inputs described in the main body of the paper. In contrast, the CL approach involves simulating realizations from the process for the short term interest rate described above, and numerically solving for the threshold that maximizes the expected present value of the net benefit from refinancing.

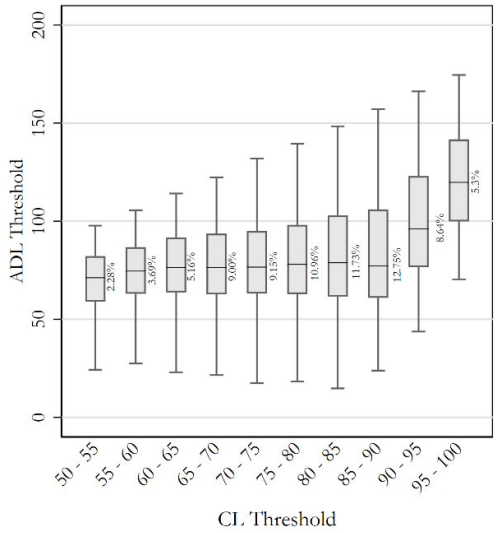
To compute the CL model thresholds, we make a few assumptions. First, we take the hazard rates that we estimate for exogenous mortgage termination (λ_{it}), and then convert them into the expected holding period (EHP) of mortgages in a straightforward fashion, i.e., for a household *i* at time *t*,

$$EHP_{it} = \frac{1}{\lambda_{it}}$$

Second, just as we do for ADL, we input the refinancing cost as a percentage of remaining mortgage principal into the CL formula, using the same assumptions that we outline in the paper.

Third, we compute the CL thresholds using monthly intervals. This is because the binomial tree which approximates the GBM in CL computations delivers increasingly accurate results as the time interval becomes shorter. Using monthly simulations, and a random sample of 100,000 mortgages from the data, we plot the relationship between the ADL and CL thresholds in the figures below, first for a wide range of thresholds that includes 98% of the sample, and second for a narrower range of thresholds below 100 basis points that includes 77% of the sample:





The two computations of the threshold, despite the considerable differences in assumptions, produce highly correlated results (the sample correlation of the two thresholds is 85%). The table below shows summary statistics of the difference between the two thresholds on this random sample:

basis points	Mean	25	50	75	Std. Dev	Correlation (ADL, CL)
ADL-CL	17.64	-8.59	13.56	39.22	34.88	0.85

The table above shows that when both the ADL and CL thresholds are small (at the 25th percentile of the distribution), the ADL threshold is slightly lower on average than the CL threshold, but for the bulk of the distribution the ADL threshold is slightly higher than the CL threshold. However, all these differences are small.

The figures show that the relationship between the ADL and CL thresholds is relatively flat in the region where the CL threshold is below about 90 basis points. The correlation between the two thresholds is much lower in this region. The reason for this is as follows. Both the ADL and CL thresholds tend to be low for larger mortgages with long remaining time to maturity. For these mortgages, the principal source of variation in the ADL and CL inputs is the exogenous termination probability.

As discussed above, this probability is captured very differently in the ADL and CL models. In the ADL model, a high termination probability corresponds to a faster reduction in the expected mortgage principal, because of the exponential hazard. In the CL model, it is instead assumed that the mortgage is terminated at a fixed future date that is moved closer in time when the termination probability is higher, given the formula for EHP. Thus, in the CL model, expected mortgage principal falls only slowly for a long time, then suddenly drops to zero.

There are offsetting effects of mortgage termination probability on the optimal threshold. On the one hand, with a deterministic interest rate, the benefits of refinancing to a lower rate are reduced if mortgage principal is falling faster over time. This raises the threshold and is the dominant effect in the ADL model, where a high termination rate implies rapidly diminishing mortgage principal in the near term. Hence, ADL thresholds are higher when the termination rate is high.

On the other hand, since the interest rate is random, a shorter mortgage maturity implies a lower option value of waiting to see if the interest rate falls even further. This lowers the threshold and is the dominant effect in the CL model. Hence, the CL thresholds are lower when the termination rate is high.

This effect reduces the correlation between the two threshold computations when the thresholds are low, and in the extreme can even make the correlation negative. That having been said, these effects on thresholds are quite small precisely because they predominantly occur at low threshold values. As we show in Online Appendix L and M, we ultimately do not get very different results with either the ADL or the CL approach to computing optimal refinancing thresholds.

Appendix L: Using Chen and Ling (1989) Thresholds

Table L1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix L we use the threshold calculation of Chen and Ling (1989). We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = exp(φ)) as a function of demographic characteristics, and exp(β) captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.844***	3.105***	2.858***
Single male household		-0.086***	0.102***
Single female household		-0.061***	-0.090***
Married household		0.000	-0.111***
Children in family		-0.084***	0.105***
Immigrant		-0.012	0.193***
Financially literate		-0.100***	-0.048*
Family financially literate		0.013	-0.118***
Getting married		-0.063**	-0.149***
Having children		-0.034**	-0.067***
Region of Northern Jutland		0.071***	-0.214***
Region of Middle Jutland		0.092***	-0.175***
Region of Southern Denmark		0.060***	-0.068***
Region of Zealand		0.069***	0.142***
Demeaned rank of:			
Age		-0.451***	0.796***
Length of education		0.217***	-0.399***
Income		0.353***	-0.777***
Financial wealth		0.449***	0.073
Housing wealth		-0.033*	-0.780***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-0.958***	0.122
Length of education		0.183***	-0.148***
Income		-0.475***	0.572***
Financial wealth		-0.469***	0.619***
Housing wealth		-0.956***	1.034***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.081	
Log likelihood		-1,334,778	
Observations		9,351,183	

Figure L1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table L1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

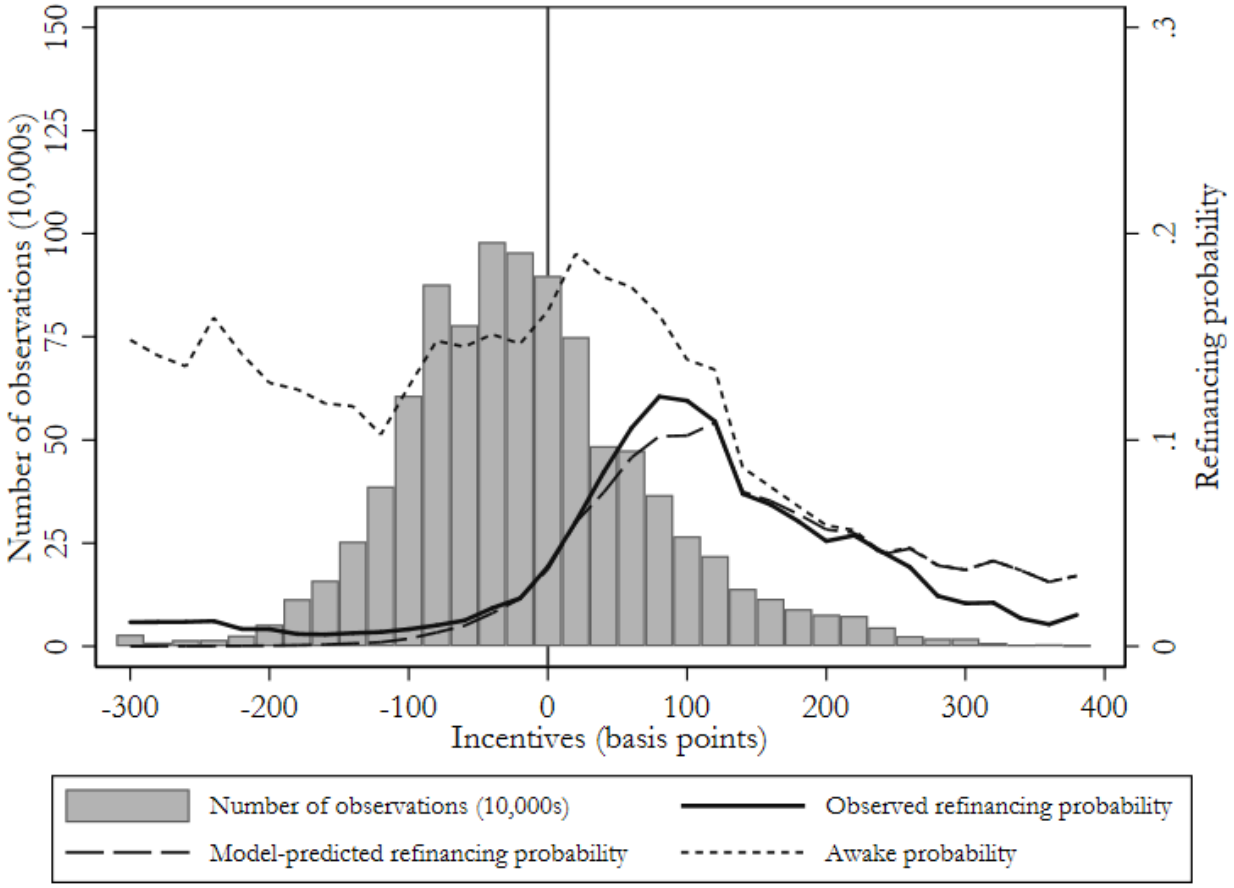


Figure L2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table L1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the option values defined by Chen and Ling (1989). Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

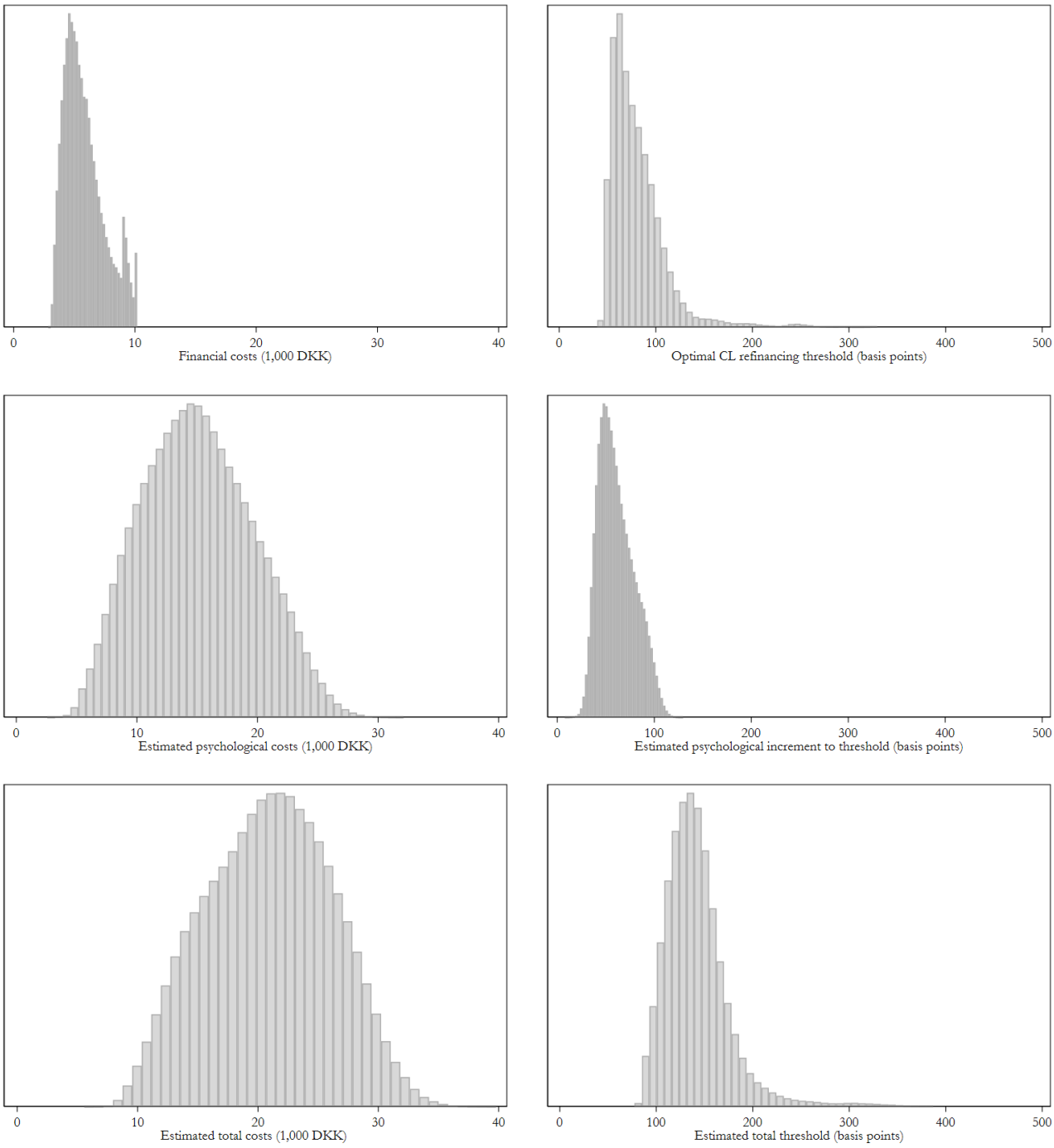


Figure L3: Model Implied Asleep Probability

This figure shows the model implied probability of households being asleep estimated using the baseline model presented in Table L1. The top panel shows a histogram of distribution of the estimated asleep probability across households, computed using a representative quarter, i.e., inputting the average mortgage age effect and average current quarter time effect estimated in the data. The bottom panel shows a box plot of the model implied estimated asleep probability for each quarter of our data, i.e., inputting the time effect and mortgage age effect for each quarter listed on the vertical axis.

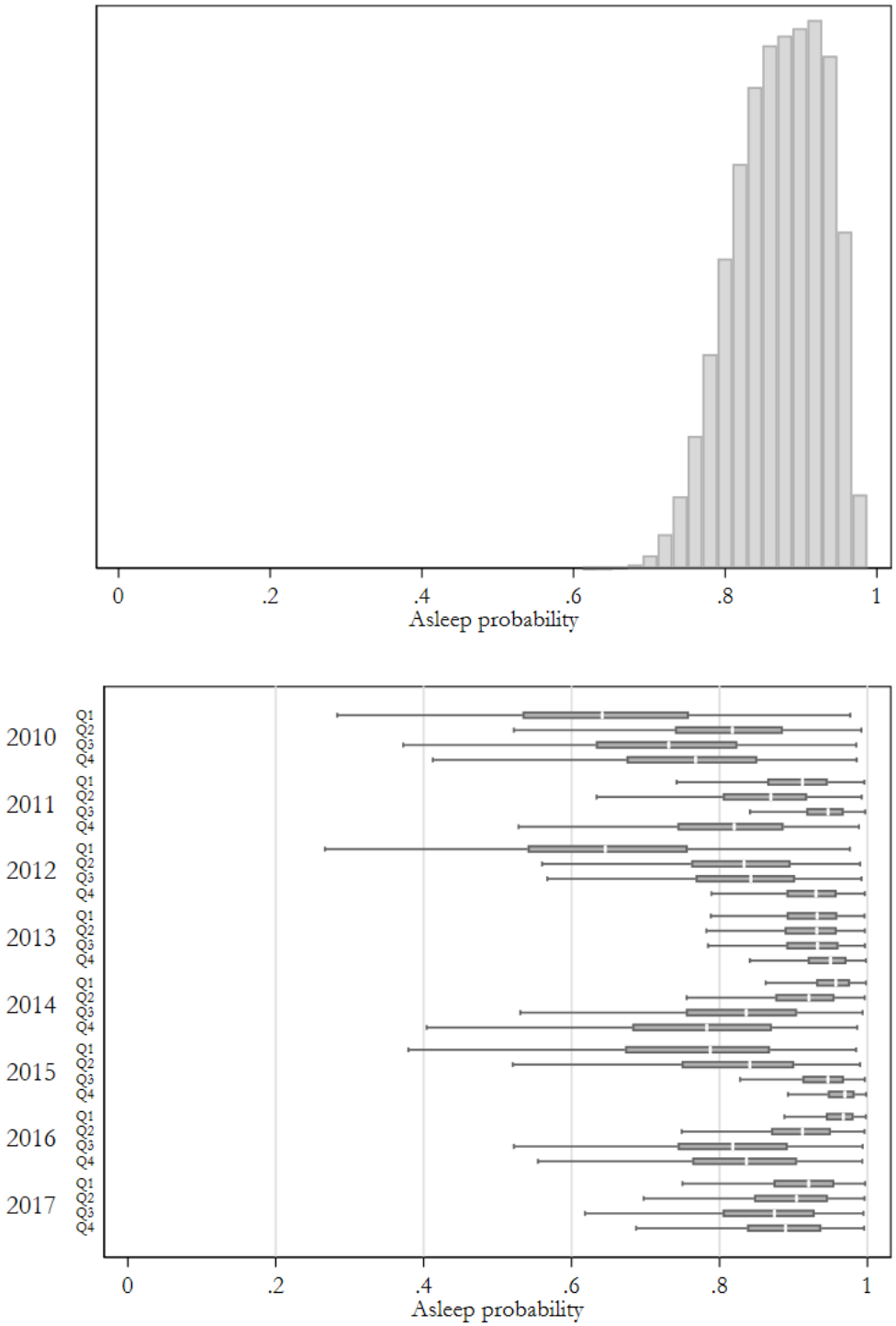
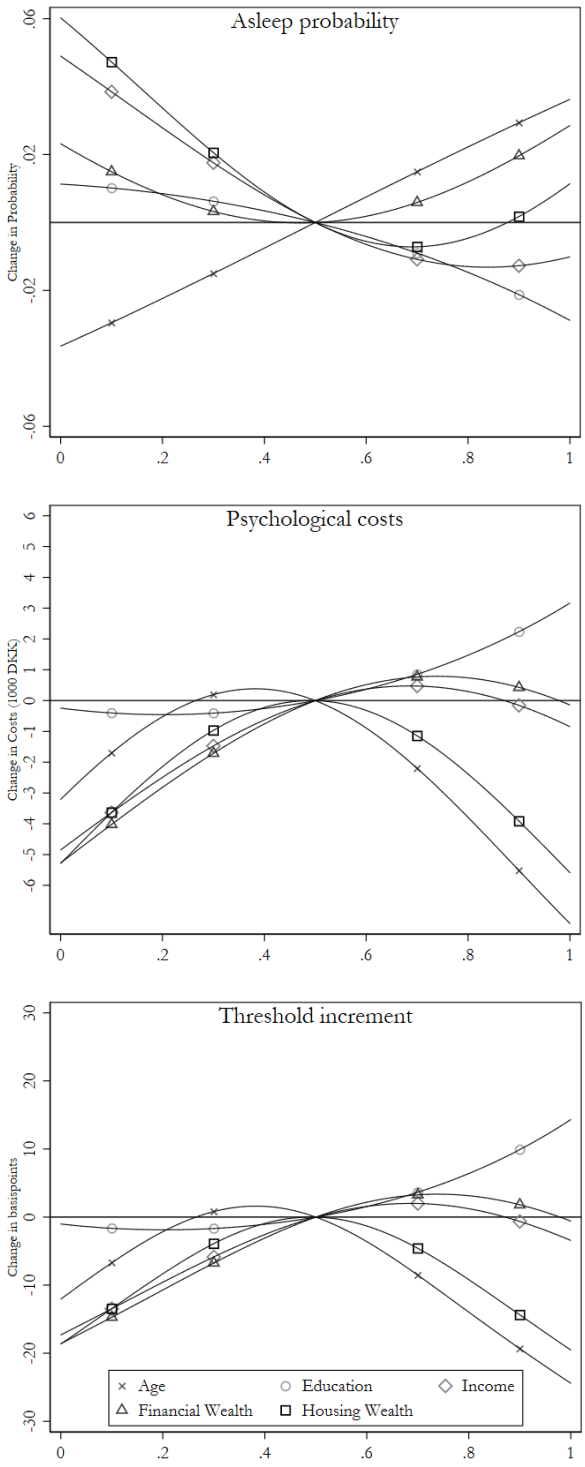


Figure L4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table L1.



Appendix M: Using Chen and Ling (1989) Thresholds - Excluding Short and Small Mortgages

Table M1: Model Estimates

In this specification, the dependent variable takes the value of 1 for a refinancing in a given quarter, and 0 otherwise. In this appendix L we use the threshold calculation of Chen and Ling (1989). We exclude all Mortgages with shorter horizons (<20 years) and all small mortgages (<0.25 M kroner principal). We estimate this specification using all households in Denmark with an unchanging number of household members, with a single fixed rate mortgage in the beginning of each year from 2010-2017. Each column reflects the estimated coefficients of our model of refinancing: χ is the probability that a household is asleep and does not respond to refinancing incentives as a function of demographic characteristics. φ captures the level of psychological refinancing costs (i.e., costs = $\exp(\varphi)$) as a function of demographic characteristics, and $\exp(\beta)$ captures the responsiveness to the incentives. The coefficients include non-linear transformations, f(x), of all the ranked control variables in addition to their levels, where $f(x) = \sqrt{2}x^2$. Pseudo R^2 is calculated using the formula $R^2 = 1 - L_1/L_0$, where L_1 is the log likelihood from the given model and L_0 is the log likelihood from a model which only allows for a constant probability of being asleep. ***, **, and * indicate coefficients that are significant at the one, five, and ten percent level, respectively, using standard errors clustered at the level of households.

	β	φ	χ
Intercept	0.909***	3.065***	2.901***
Single male household		-0.089***	0.097***
Single female household		-0.065***	-0.094***
Married household		0.004	-0.109***
Children in family		-0.081***	0.097***
Immigrant		-0.007	0.187***
Financially literate		-0.098***	-0.054*
Family financially literate		0.012	-0.116***
Getting married		-0.057*	-0.156***
Having children		-0.028*	-0.069***
Region of Northern Jutland		0.064***	-0.204***
Region of Middle Jutland		0.084***	-0.165***
Region of Southern Denmark		0.051***	-0.057***
Region of Zealand		0.059***	0.146***
Demeaned rank of:			
Age		-0.469***	0.769***
Length of education		0.190***	-0.370***
Income		0.358***	-0.753***
Financial wealth		0.465***	0.073**
Housing wealth		-0.095***	-0.739***
Non-linear transformation f(x), x is the demeaned rank of:			
Age		-0.962***	0.055
Length of education		0.171***	-0.126**
Income		-0.471***	0.573***
Financial wealth		-0.492***	0.611***
Housing wealth		-0.975***	1.010***
Current quarter dummies			Yes
Mortgage age dummies			Yes
Pseudo R^2		0.084	
Log likelihood		-1,253,826	
Observations		9,052,396	

Figure M1: Refinancing, Incentives and Model Implied Refinancing Probabilities

This figure plots refinancing probabilities from the baseline model presented in Table M1, as a function of refinancing incentives, alongside the number of observations at each level of incentives. The bars in this figure show the number of household-quarters (scale on the left vertical axis) and the lines show the fraction of these household-quarters that refinance (scale on the right vertical axis) at each level of refinancing incentives shown on the horizontal axis. The bars are 20-basis-point incentive intervals centered at the points on the horizontal axis. The solid line shows the actual refinancing probability observed in the data, the long-dashed line shows the model-predicted refinancing probability, and the short-dashed line shows the fraction of households that the model estimates are not asleep (i.e., awake) in each period.

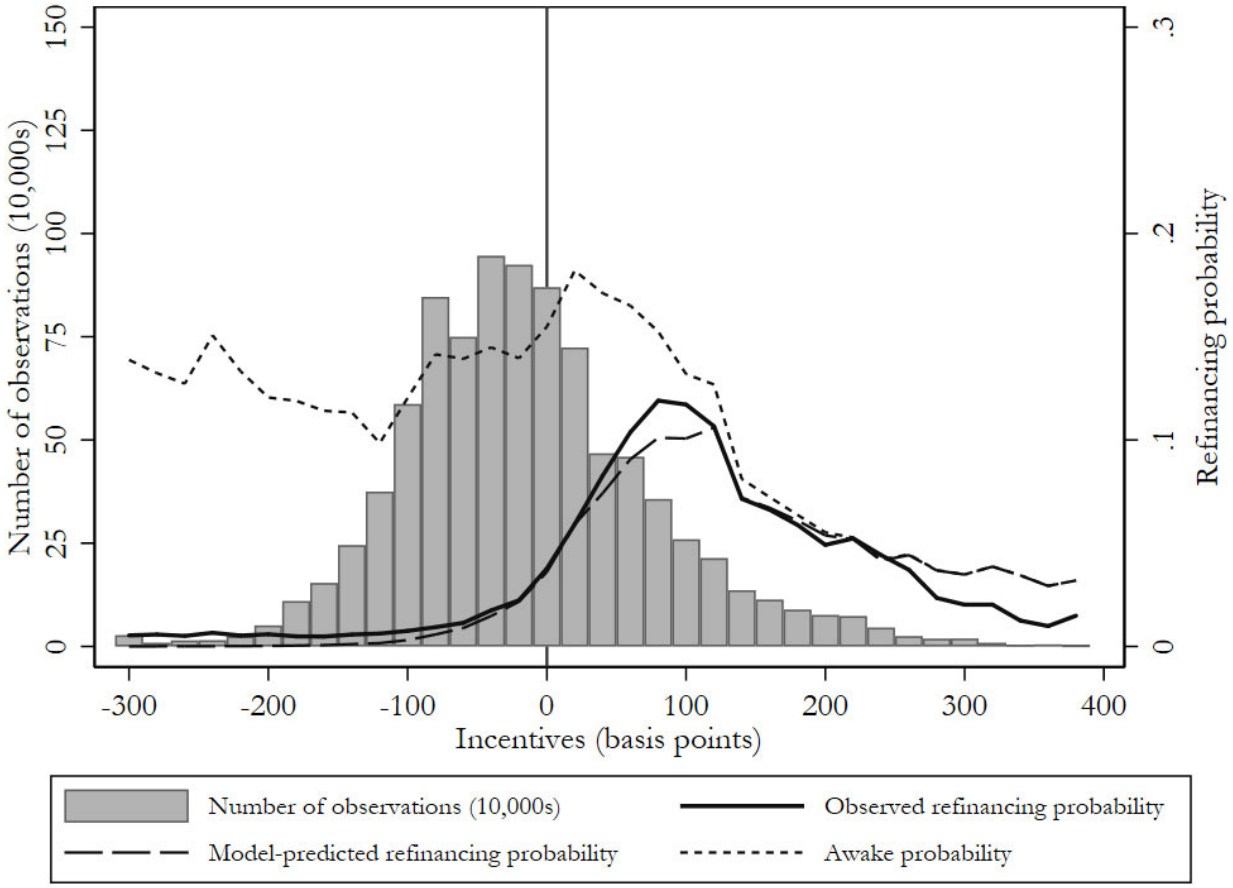


Figure M2: Model Characteristics

These figures summarize the costs of refinancing estimated from the baseline model presented in Table M1 over the entire sample period. The three plots on the left show the costs in 1,000 DKK, while the three plots on the right show these costs in the form of the implied interest rate threshold in basis points that they translate into using the option values defined by Chen and Ling (1989). Descending vertically, the first row shows the pure financial costs of refinancing, which are based on mortgage size. The second row shows the estimated psychological costs of refinancing, while the third row is the total costs, which sum the two rows above it.

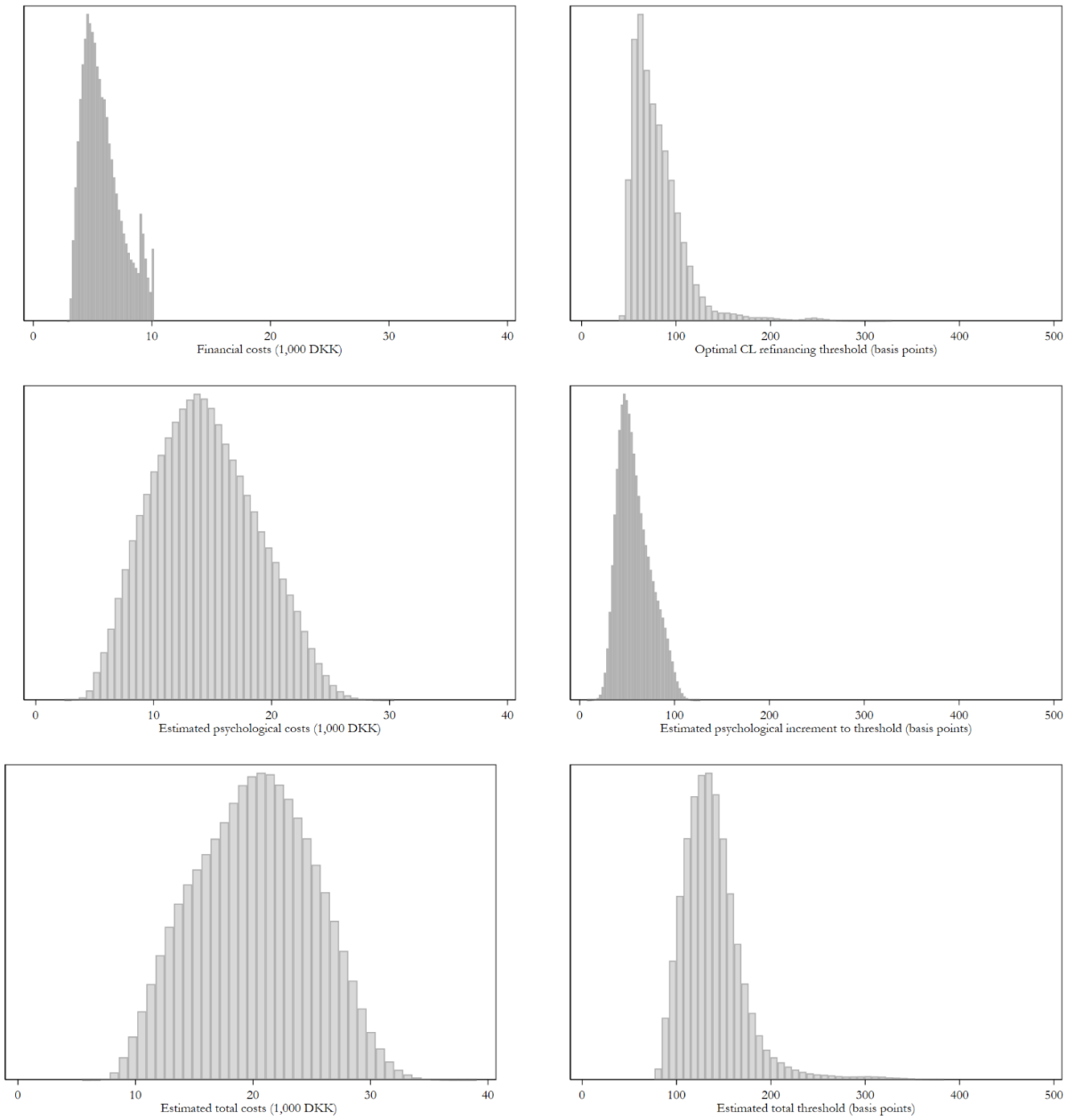


Figure M3: Model Implied Asleep Probability

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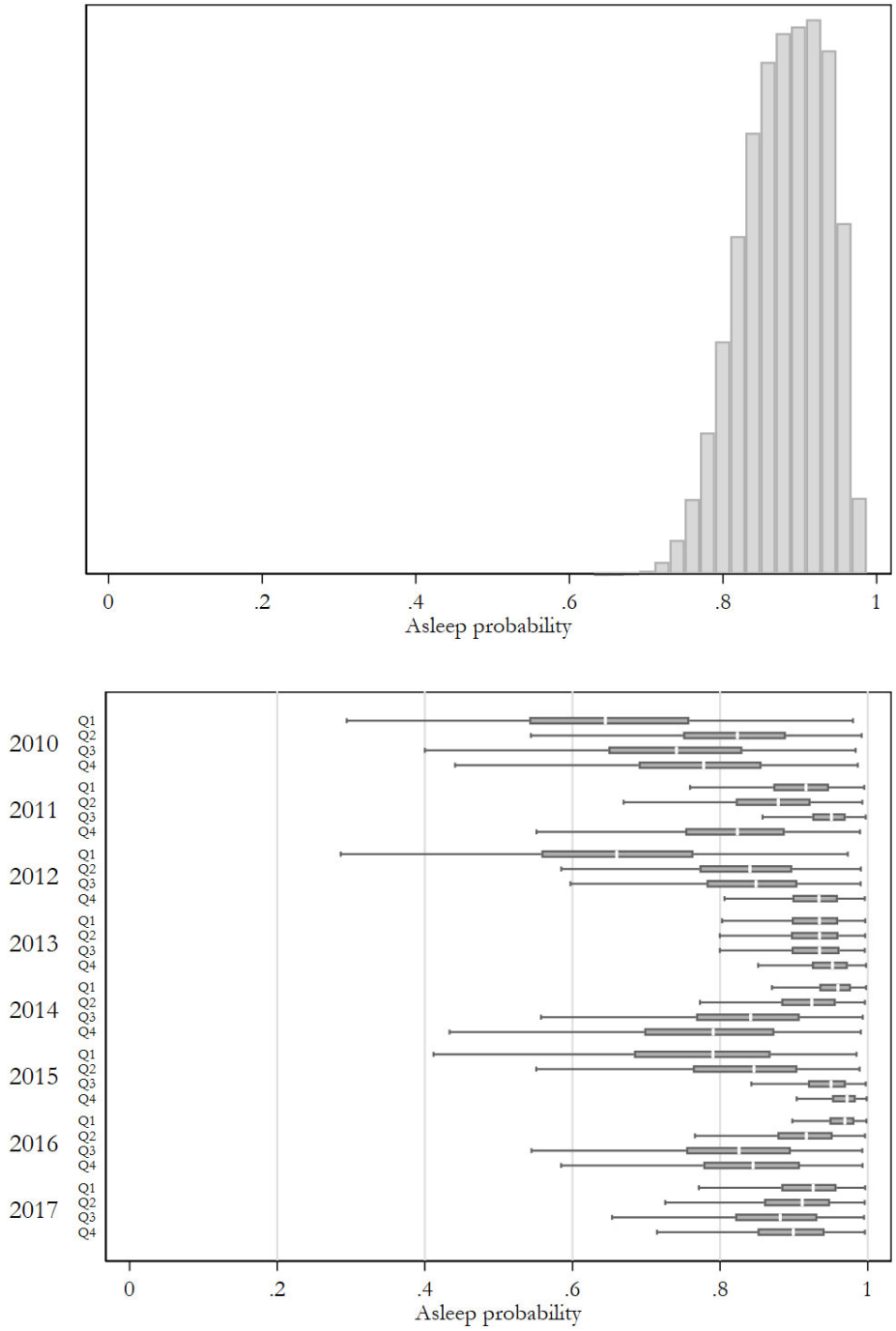
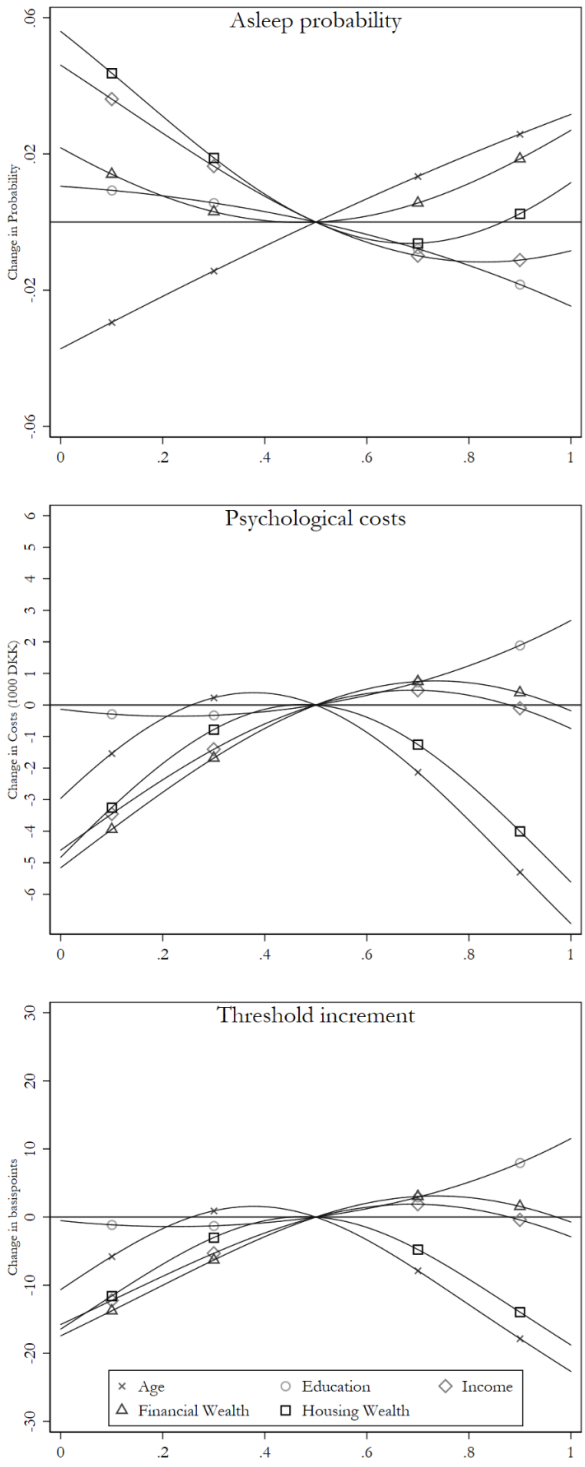


Figure M4: Marginal Effects of Ranked Variables

This figure shows the marginal change in the probability of being asleep, the estimated psychological costs of refinancing measured in 1,000 DKK, and the additional psychological cost increment to the interest-rate threshold to be surmounted to induce a household to refinance as a function of selected ranked variables: age, education, income, financial wealth, and housing wealth. To plot these marginal effects, we use the household-level fitted values of the baseline model presented in Table M1.



Appendix N: ADL Threshold, Interest Rate Saving and Refinancing Incentive among Prompt Refinancers

This table reports the average ADL threshold, the interest rate saving, and the refinancing incentive among prompt refinancers. Prompt refinancers are defined as the first 2.5%, 5% and 10% of households in each mortgage cohort that refinances, respectively. The table reports statistics for all prompt refinancers, and sorted on mortgage size, maturity, and age quintiles.

	2.5%			**5%**			**10%**		
	Threshold	Saving	Incentive	Threshold	Saving	Incentive	Threshold	Saving	Incentive
All	71.8	95.7	24.0	68.0	117.2	49.3	67.0	131.0	64.0
Mortgage size quintile									
1	106.1	89.5	-16.5	95.8	115.5	19.7	90.6	131.2	40.7
2	86.2	94.5	8.3	79.1	117.4	38.4	76.5	131.2	55.1
3	78.2	96.1	17.9	72.8	118.3	46.5	69.0	131.1	62.4
4	72.2	97.0	24.8	66.3	118.0	51.7	63.9	131.0	67.1
5	63.1	95.9	32.8	59.1	116.5	57.3	57.6	130.3	72.7
Maturity quintile									
1	77.2	75.6	-1.5	72.4	105.8	33.4	71.3	119.6	48.3
2	67.6	94.0	26.4	64.6	116.3	51.7	64.3	130.3	66.0
3	68.4	97.3	28.9	66.2	118.2	52.0	66.7	129.5	62.8
4	74.9	101.5	26.6	71.5	122.8	51.3	71.8	129.3	57.6
5	74.3	107.0	32.7	70.4	127.0	56.5	73.3	145.5	71.7
Age quintile									
1	78.5	97.1	18.5	73.9	118.2	44.3	73.2	132.2	58.9
2	67.1	95.1	28.0	64.2	116.6	52.4	63.6	130.0	66.6
3	66.7	93.0	26.3	63.9	115.2	51.3	63.4	129.4	66.0
4	67.8	96.0	28.1	65.2	117.3	52.1	65.0	130.9	65.9
5	71.4	97.2	25.8	68.2	119.4	51.2	68.2	132.9	64.6

Appendix O: Simulation of Misspecified Choice Models

To examine the robustness of our finite mixture model we estimate our mixture model on simulated data of misspecified refinancing choices. To mimic our natural data we simulate the refinance choice of 1 million individuals with three covariates, (*i*) a ranked variable uniformly distributed between -0.5 and 0.5, (*ii*) a dummy that takes a unit value in 50% of the sample, and (*iii*) a cross-sectionally varying mortgage termination probability with a left tailed skewed beta distribution with mean 0.10 per year and standard deviation 0.07, roughly in line with the variation in mortgage termination probabilities in our Danish data. To isolate the importance of model misspecification, we simplify and assume no correlation between covariates.

We randomly allocate a mortgage to each individual with coupon rates normally distributed with mean 6% and standard deviation 1%. The mortgages have maturities between 5 and 30 years, distributed as a truncated right skewed beta distribution with mean 24 years and standard deviation 4.7 years, and uniformly distributed remaining principal between 0 and 3 million kroner. All mortgage characteristics are simulated with zero cross-sectional correlation.

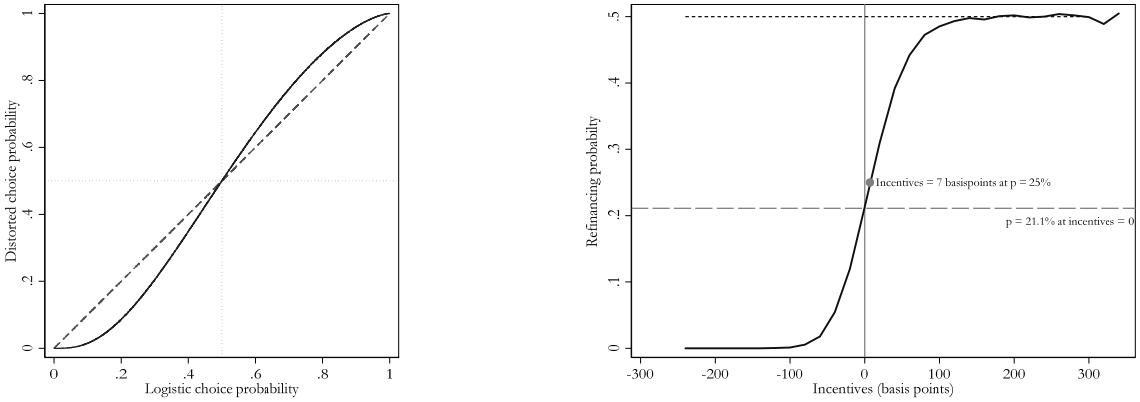
For the refinancing decision we apply our standard assumptions: discount rate $\rho = 0.05$, mortgage interest volatility $\sigma = 0.0074$, marginal tax rate $\tau=0.33$, and a stochastic logistically distributed choice error (with variance $\beta=1$). Additionally, we assume inflation of 2% and a current market interest rate of 4.5%. We simulate several different datasets to graphically display how misspecified choice rules affect our estimation procedures. In all datasets we simulate data in which covariates have no effects on the refinancing decision, but where the probability of being asleep in any period is 0.5 ($\chi_{constant} = 0$), and there is a fixed 1,000 DKK psychological refinancing cost that is added to the financial cost of refinancing ($\varphi_{constant} = 0$).

We have verified that when there is no misspecification, our estimation procedures recover parameters that are very close to the true parameters of the model. In this appendix, we introduce misspecification by distorting the stochastic choice probability away from the logistic choice probability p. Specifically, we assume that the stochastic choice probability is given by the function $w(p) = e^{-\alpha(-\log(p))^{\varsigma}}$ following Prelec (1998). In dataset A we specify the distorted probability to be lower than the logistic probability when $p<0.5$ and higher when $p>0.5$. In dataset B we specify the distorted probability to be higher than the logistic probability when $p<0.5$ and lower when $p>0.5$. In dataset C we specify the distorted probability to be everywhere lower than the logistic probability, downward biasing subjective choice probabilities.

Figure N1 displays the distorted choice probabilities and observed choice patterns, and reports the estimated coefficients of interest. The distortions in datasets A and B have very little impact on either average choices or the coefficients on covariates. The distortion in dataset C creates significant upward bias in both the average probability that a household is asleep, and the average psychological refinancing cost. This is unsurprising since this distortion reduces refinancing probabilities among all households. However, once again the estimated coefficients on covariates are very similar to their true values. We conclude that our estimates of cross-sectional variation in time-dependent and state-dependent inaction are robust to reasonable variation in the functional form assumed for the stochastic choice error.

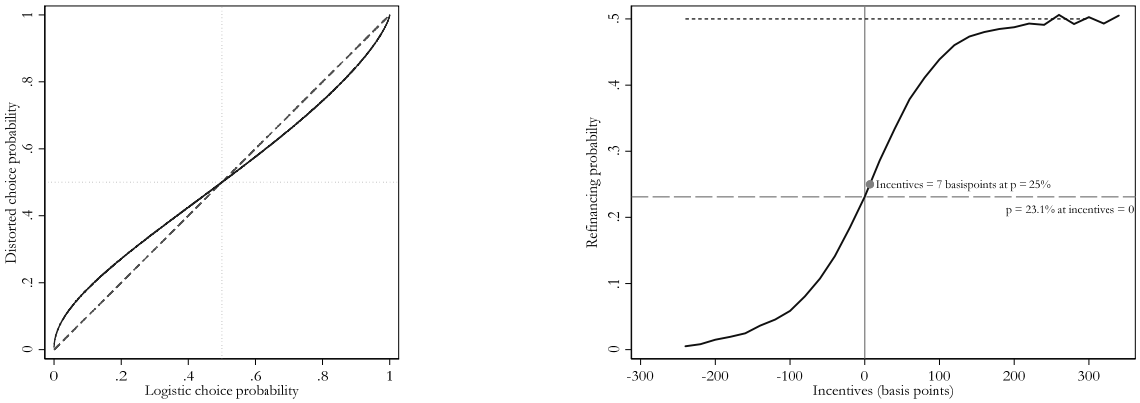
Figure O1: Estimation of Misspecified Choice Models

Dataset A



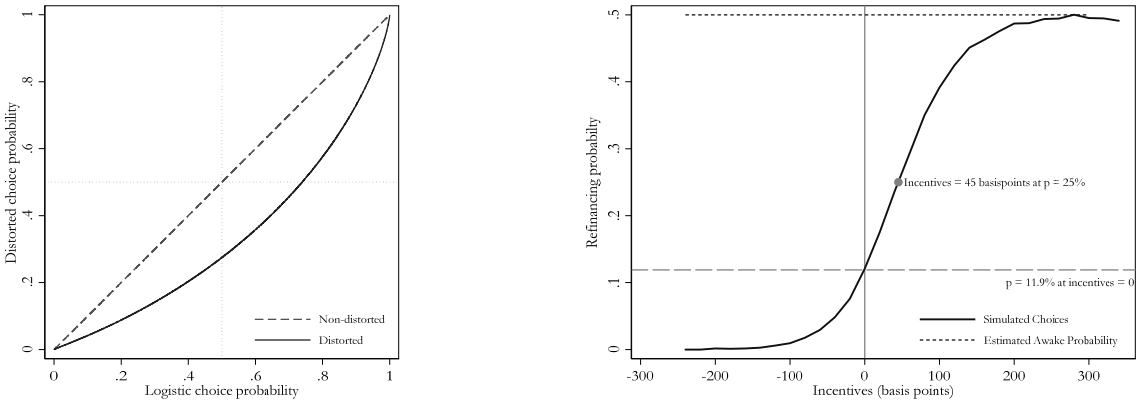
In dataset A we estimate $\chi_{constant} = 0.017$, resulting in an insignificant positive bias of 0.4 percentage point in the probability of time-dependent inaction. We estimate $\varphi_{constant} = 0.075$, resulting in an insignificant positive bias of 7 DKK in the psychological refinancing cost (that is, we estimate the cost to be 1,007 DKK rather than 1,000 DKK). The implied average threshold is 7 basis points above the ADL threshold. None of the covariates are estimated significantly different from zero. The point estimates are $\chi_{ranked} = 0.0242$, $\chi_{dummy} = -0.005$, $\varphi_{ranked} - 0.169$, and $\varphi_{dummy} = 0.005$.

Dataset B



In dataset B we estimate $\chi_{constant} = -0.004$ resulting in an insignificant negative bias of -0.1 percentage point in the probability of time-dependent inaction. We estimate $\varphi_{constant} = -0.250$, resulting in an insignificant negative bias of -220 DKK in the psychological refinancing cost. The implied average threshold is still 7 basis points above the ADL threshold. None of the covariates are estimated significantly different from zero. The point estimates are $\chi_{ranked} = 0.031$, $\chi_{dummy} = 0.018$, $\varphi_{ranked} = -0.171$, and $\varphi_{dummy} = 0.116$.

Dataset C



In dataset C we estimate $\chi_{constant} = 0.268$, resulting in a significant positive bias of 6.6 percentage points in the probability of time-dependent inaction. We estimate $\varphi_{constant} = 1.084$, resulting in a significant positive bias of 1955 DKK in the estimated psychological refinancing cost. The implied average threshold is 45 basis points above the ADL threshold. None of the covariates are estimated significantly different from zero. The point estimates are $\chi_{ranked} = -0.020$, $\chi_{dummy} = -0.017$, $\varphi_{ranked} = 0.023$, and $\varphi_{dummy} = 0.050$.