PRESENT BIAS AND MORTGAGE REFINANCING DECISIONS

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This paper studies the optimal mortgage refinancing problem of a behavioral household that is present-biased and inattentive to mortgage rates. In solving the problem, I derive the first closed-form optimal refinancing rule of a behavioral household, enabling the estimation of the model. I estimate the model based on Danish administrative data, showing that it can endogenously explain delays in mortgage refinancing. I find substantial evidence of present bias among households, with the average household having a short-run discount factor of $\beta = 0.39$. Older, less-educated, financially wealthier, and higher-income households exhibit stronger present bias, whereas higher housing wealth and financial literacy reduce this behavioral bias. Implications for the refinancing channel of monetary policy transmission are discussed.

Keywords: household finance, present bias, inattention, mortgage, refinance, option value.

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1. Introduction

The decision to refinance a mortgage is one of the most substantial financial choices households face, with major consequences for both individual welfare and the efficiency of monetary policy through interest rate changes. Recent literature documents that households often fail to refinance their mortgage optimally; however, little is known about the underlying determinants that are leading to this behavior (see, e.g., Agarwal et al., 2016; Keys et al., 2016; Andersen et al., 2020; Gerardi et al., 2023). Evidence from other financial decisions suggests that households are present-biased when faced with decisions between immediate and delayed costs and benefits (see, e.g., Laibson et al., 2020; Cohen et al., 2020). Given that optimal refinancing crucially depends on a tradeoff between refinancing costs now and potential savings in the future, the question arises whether and to what extent present bias causes delays in mortgage refinancing.

To address this open question, I study the mortgage refinancing problem of a present-biased household. Following Campbell's (2006) positive approach to household finance, I first enrich the fully rational refinancing model of Agarwal et al. (2013; henceforth, ADL) with two behavioral factors, namely present bias and inattention to mortgage rates. I then solve this behavioral refinancing model, deriving the first closed-form optimal refinancing rule of a behavioral household.

The optimal refinancing rule depends on the refinancing costs, mortgage value, standard deviation of the mortgage rate, expected mortgage repayment rate, time preferences, and level of inattention. It specifies an interest rate differential at which refinancing becomes optimal. Once this optimal refinancing differential is reached, however, inattentive households refinance only with a certain probability. Present bias increases the optimal refinancing differential compared to ADL's rational counterpart, while inattention has the opposite effect. Hence, the model endogenously covers commonly observed refinancing mistakes of choosing a wrong refinancing differential or delaying refinancing.

I estimate the model based on Danish administrative household and mortgage data between 2009 and 2017, showing that the model can explain the observed refinancing behavior. I find substantial evidence of present bias among households, with the average household having a short-run discount factor of $\beta = 0.39$. Older, less-educated, financially wealthier, and higher-income households exhibit stronger present bias, whereas higher housing wealth and financial literacy reduce this behavioral bias. The average household is also inattentive to mortgage rates and considers refinancing only with a probability of 10% each quarter. Older, less-educated, and financially wealthier households are less attentive to mortgage rates, whereas higher income, housing wealth, and financial literacy increase the attention.

The findings have important implications for the refinancing channel of monetary policy transmission. The efficiency of this channel depends on households' ability to respond appropriately to changes in interest rates. The results indicate that present bias and inattention lead to delays in mortgage refinancing, which can weaken the effectiveness of interest rate cuts in stimulating household consumption and investment. Hence, the results suggest that policymakers should consider present bias and inattention when designing and evaluating monetary policy measures, particularly regarding their expectations about the effects of interest rate changes on household refinancing behavior.

The results also shed new light on the distributional consequences of monetary policy. The observed variation in present bias and inattention across different demographic groups implies that responses to interest rate cuts can diverge significantly. This suggests that interest rate changes may have unequal effects across various socioeconomic groups, adding depth to the ongoing discussion on the distributional consequences of monetary policy (see, e.g., Daly, 2020; Feiveson et al., 2020; Wong, 2021).

This paper contributes to three strands of literature. First, the paper adds to recent literature on mortgage refinancing mistakes (see, e.g., Agarwal et al., 2016; Keys et al., 2016; Bajo and Barbi, 2018; Johnson et al., 2019; Andersen et al., 2020; Gerardi et al., 2023).[1] While previous studies mainly document refinancing mistakes and observe deviations from ADL's optimal refinancing rule, this paper extends the ADL model to a behavioral refinancing model, taking into account present bias and inattention, which can explain the observed refinancing mistakes.

Within the literature on mortgage refinancing mistakes, the paper is most closely related to Andersen et al. (2020). They also study mortgage refinancing in Denmark but estimate a purely empirical model, which attributes deviations from ADL's optimal refinancing rule to a probability of households being inattentive each period and psychological refinancing costs. This paper, on the other hand, derives the optimal refinancing rule of a present-biased and inattentive household, enabling the estimation of a structural refinancing model and attributing refinancing mistakes to present bias and inattention.

Second, the paper is related to macroeconomic literature on frictions in the refinancing channel of monetary policy (see, e.g., Beraja et al., 2019; Laibson et al., 2021; Berger et al., 2021, 2022; Eichenbaum et al., 2022; Byrne et al., 2023). While inattention is a common model ingredient within this literature, only Laibson et al. (2021) use present bias to understand frictions in the refinancing channel. Laibson et al. (2021) examine the effectiveness of macroeconomic policy theoretically in a heterogeneous-agent model with present bias and find that present bias slows

[1] Earlier literature also explores the mortgage prepayment behavior of households and its implications for the valuation of mortgage-backed securities (see, e.g., Schwartz and Torous, 1989; Stanton, 1995; Deng et al., 2000).

down monetary policy transmission through the refinancing channel. Complementing Laibson et al. (2021), this paper provides empirical support that present bias influences mortgage refinancing decisions and highlights the importance of present bias for the efficiency of the refinancing channel.

Finally, the paper contributes to literature that measures time preferences (see, e.g., Ashraf et al., 2006; Meier and Sprenger, 2010; Augenblick, 2018; Laibson et al., 2020; and the review by Cohen et al., 2020). While there is empirical evidence that present bias affects, for example, household consumption-savings decisions (Ashraf et al., 2006), credit card usage (Meier and Sprenger, 2010), and completion of unpleasant tasks (Augenblick, 2018), this paper is the first to empirically investigate the effect of present bias on mortgage refinancing decisions. This paper finds substantial evidence of present bias with an average short-run discount factor of $\beta = 0.39$ for a given long-run discount rate of $\rho = 0.05$, which is broadly in line with recent findings of Laibson et al. (2020).[2]

The rest of the paper is organized as follows. Section 2 introduces the behavioral model of mortgage refinancing with present bias and inattention, Section 3 deals with the structural estimation of this model, and Section 4 concludes the paper.

2. Model

In this section, I introduce the behavioral refinancing model. First, I extend the ADL framework to a behavioral model, including present bias and inattention to mortgage rates. Second, I derive the key result of the paper, a closed-form optimal refinancing rule of a behavioral household. Finally, I discuss the effect of present bias and inattention on mortgage refinancing decisions. Appendix A contains the corresponding proof.

ADL framework. Following ADL, the real mortgage interest rate r and the inflation rate π are Brownian motions given by

$$\begin{aligned} \mathrm{d}r_t &= \sigma_r \mathrm{d}W_t^r\ , \\ \mathrm{d}\pi_t &= \sigma_\pi \mathrm{d}W_t^\pi\ , \end{aligned}$$

where $\sigma_r, \sigma_\pi > 0$ and W^r and W^π are Wiener processes with covariance $\sigma_{r\pi}$. Therefore, the nominal mortgage interest rate $i = r + \pi$ is also a Brownian motion with volatility $\sigma = \sqrt{\sigma_r^2 + \sigma_\pi^2 + 2\sigma_{r\pi}}$.[3]

A household holds a fixed-rate mortgage (FRM) with nominal interest rate m.

[2] Laibson et al. (2020) estimate a structural life-cycle model of consumption and savings with present bias and find a short-run discount factor of $\beta = 0.5$ and a long-run discount rate of $\rho = 0.01$.

[3] See ADL and Andersen et al. (2020) for a discussion of this assumption.

It has the option to refinance repeatedly at the current nominal mortgage interest rate against payment of real refinancing costs $C(M) > 0$, where $M > 0$ is the real mortgage value. Interest deductions can be incorporated into the model by considering normalized refinancing costs of the form $C(M) = \frac{\kappa(M)}{1-\tau}$, with real (tax-adjusted) refinancing costs $\kappa(M) > 0$ and marginal tax rate $0 \le \tau < 1$, see ADL. The mortgage value M is counterfactually assumed to be constant until an exogenous repayment event at T, where T is a stopping time with arrival intensity $\lambda > 0$. The exogenous repayment rate λ indirectly accounts for the decline of the real mortgage value over time through exogenous mortgage termination (for example, due to relocation), principal repayment, and inflation.[4]

Inattention. In extension to ADL, households pay attention to current mortgage interest rates only with rate $\gamma > 0$.[5] Formally, I consider admissible refinancing policies ξ of the form

$$\mathrm{d}\xi_t = \theta_t \mathrm{d}N_t \,,$$

where N is a Poisson process with arrival intensity γ and θ a predictable process which takes only values 0 or 1.[6] Consequently, the household is only attentive at the jump times of N at which it chooses to keep the old contract ($\theta_t = 0$) or to refinance into a new one ($\theta_t = 1$). The associated mortgage rate of the household m is given by

$$\mathrm{d}m_t = (i_t - m_{t-})\,\mathrm{d}\xi_t \,.$$

Hence, the mortgage rate of the household switches to the current nominal mortgage interest rate each time the household refinances and otherwise remains constant.

Time preferences. I assume that households are risk neutral as in ADL, but have present-biased time preferences. Here, present bias is generated by a quasi-hyperbolic discount function, which generally deviates from the standard exponential discount function. Following Harris and Laibson (2013), I use instantaneous-gratification (IG) time preferences to model quasi-hyperbolic discounting in a continuous-time framework.[7]

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4 ADL show how the exogenous repayment rate λ can be calibrated so that the model reproduces a realistic mortgage contract.

5 That is, I use a "Calvo" model of inattention (Calvo, 1983; Gabaix, 2019), a common approach in the mortgage literature to produce time-dependent inaction (see, e.g., Andersen et al., 2020; Laibson et al., 2021; Berger et al., 2021, 2022).

6 This formulation is equivalent to a situation in which the household perceives the mortgage interest rate only at random attention times which arrive with intensity γ.

7 Harris and Laibson (2013) introduce IG time preferences in a consumption-savings model.

The real discount function of an IG household at time t is given by

$$D(t,s) = \begin{cases} 1, & s = t, \\ \beta e^{-\rho(s-t)}, & s \in (t,\infty), \end{cases}$$

with long-run discount rate $\rho > 0$ and short-run discount factor $0 < \beta \leq 1$.[8] In the case of $\beta < 1$, the IG discount function implies high short-run discount rates in contrast to low long-run discount rates, leading to time-inconsistent preferences. The special case $\beta = 1$ reproduces the conventional, time-consistent, exponential discount function.

The IG model is the limiting case of the present-future (PF) model of time preferences (Harris and Laibson, 2013).[9] In the PF model, self n of the household makes the decisions during the time interval $[t_n, t_{n+1})$, where the lifespan of self n, $s_n = t_{n+1} - t_n$, is exponentially distributed with intensity $\mu > 0$ and $t_0 = 0$. Self n cares about decisions of future selves but cannot control them. The real discount function of self n at time $t \in [t_n, t_{n+1})$ is given by

$$d_n(t,s) = \begin{cases} e^{-\rho(s-t)}, & s \in [t, t_{n+1}), \\ \beta e^{-\rho(s-t)}, & s \in [t_{n+1}, \infty). \end{cases}$$

A PF household minimizes the subjective value of its real mortgage payments,[10] hence, faces the optimization problem

$$v(r,\pi,m) = \inf_{\xi} \mathbb{E}_{r,\pi,m}\Big[\int_0^T d(t)((m_t - \pi_t)M\,\mathrm{d}t + C(M)\,\mathrm{d}\xi_t) + \mathbb{1}_{T<\infty} d(T)M\Big]. \quad (2.1)$$

In particular, the refinancing problem is an intra-personal game in which decisions of the household are made by different selves over time. As a consequence, the refinancing decision of a self depends strongly on its expectation of the behavior of future selves.

Solution. The paper focuses on solving the refinancing problem of an IG household, that is, considers the limiting case $\mu \to \infty$.[11] Moreover, I follow Harris and Laibson (2013) in restricting the focus on finding a stationary Markov-perfect equilibrium, that is, to the case where all selves choose the same strategy. In this case, the

[8] In comparison, the discrete-time version of the quasi-hyperbolic discount function is given by $1, \beta\delta, \beta\delta^2, \beta\delta^3, \ldots$ (Laibson, 1997).

[9] In this paper, present bias refers to IG time preferences unless otherwise noted.

[10] With a slight abuse of notation, I suppress the dependence of the value function and the discount function of the PF household on the current self n and the current time t in the following. Note that all selves face the same problem and that the problem is time-independent.

[11] The PF discount function converges to the IG discount function for $\mu \to \infty$, that is, $\lim_{\mu\to\infty} d(t) = D(t)$. Here, I suppress the dependence of the IG discount function on the current time as well.

household is aware of its present bias, and therefore, each self of the household correctly assumes that future selves will exhibit the same behavior as itself. This is commonly referred to as sophisticated present bias, in contrast to (partially) naive present bias, where each self is (partially) unaware of the present bias of future selves.

Proposition 2.1 states the stationary solution of the refinancing problem of an IG household. Here, x denotes the difference between the nominal mortgage interest rate i and the nominal mortgage rate of the household m, that is, $x = i - m$. Further, V represents the value function of the IG household.

Proposition 2.1. *The value function V of the IG household satisfies $V = \beta V_C$ with*

$$V_C(r, \pi, m) = \begin{cases} -K_1 e^{\psi_1 x} + \frac{\gamma M x}{(\rho+\lambda)(\rho+\lambda+\gamma)} + \frac{\gamma(C(M)-K_0)}{\rho+\lambda+\gamma} + \frac{(m-\pi+\lambda)M}{\rho+\lambda}, & x \leq x^*, \\ -K_0 e^{-\psi_0 x} + \frac{(m-\pi+\lambda)M}{\rho+\lambda}, & x > x^*, \end{cases} \tag{2.2}$$

$$x^* = \frac{-1}{\psi_0}\left[\phi + W(-\chi \exp(-\phi))\right], \tag{2.3}$$

where W is the principal branch of the Lambert W-function and

$$\begin{aligned} \phi &= \chi + \psi_0(\rho+\lambda)\frac{C(M)}{\beta M}, & \chi &= \frac{\gamma\psi_0[\beta M + (1-\beta)C(M)(\rho+\lambda)\psi_1]}{\beta M[(\rho+\lambda+\gamma)\psi_0 + (\rho+\lambda)\psi_1]}, \\ K_0 &= \frac{M(\phi+\psi_0 x^*)}{\psi_0(\rho+\lambda)}, & K_1 &= \frac{\gamma[\beta M - (1-\beta)C(M)(\rho+\lambda+\gamma)\psi_0]e^{-\psi_1 x^*}}{\beta[(\rho+\lambda+\gamma)\psi_0 + (\rho+\lambda)\psi_1](\rho+\lambda+\gamma)}, \\ \psi_0 &= \frac{\sqrt{2(\rho+\lambda)}}{\sigma}, & \psi_1 &= \frac{\sqrt{2(\rho+\lambda+\gamma)}}{\sigma}. \end{aligned} \tag{2.4}$$

The optimal refinancing policy is given by $\xi_t^* = \int_{[0,t)} \mathbb{1}_{x_s \leq x^*} \, \mathrm{d}N_s$.

In other words, for a present-biased household, refinancing is optimal when the prevailing nominal mortgage interest rate drops at least by $-x^*$ below the nominal mortgage rate of the household. However, the household does not refinance immediately when it is optimal, but only with intensity γ. Note that the value function V is equal to β times the continuation value function V_C. The continuation value function V_C corresponds to the expected present discounted value of the household's real mortgage payments, exponentially discounted at rate ρ.

Discussion. The key result of the paper, the optimal refinancing threshold x^*, precisely describes how a behavioral household trades off the costs and potential savings from refinancing.[12] Figure 1 illustrates that present bias leads to higher optimal refinancing thresholds, whereas inattention has the opposite effect. The top

[12] For simplicity, the term optimal refinancing threshold refers to the absolute value of x^* in the following, see ADL.

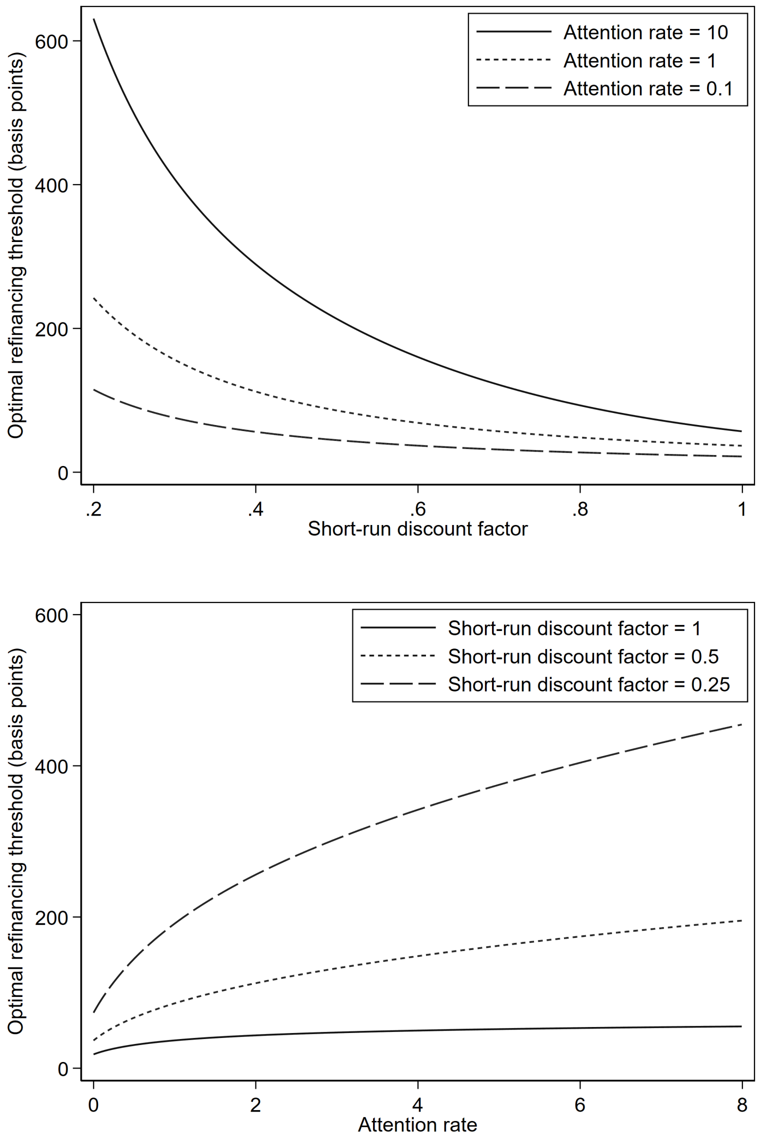


Figure 1: Optimal refinancing threshold, present bias, and inattention. This figure illustrates the optimal refinancing threshold for a household with sample average mortgage characteristics and different present bias and inattention parameters. The top plot shows the optimal refinancing threshold as a function of the short-run discount factor for attention rates of 10 (solid), 1 (short-dashed), and 0.1 (long-dashed), respectively. The bottom plot shows the optimal refinancing threshold as a function of the attention rate for short-run discount factors of 1 (solid), 0.5 (short-dashed), and 0.25 (long-dashed), respectively.

panel of Figure 1 plots the optimal refinancing threshold as a function of the short-run discount factor β for a household with sample average mortgage characteristics and different values for the attention rate γ.[13] The figure shows that the optimal refinancing threshold increases with decreasing short-run discount factor and that the functions of the optimal refinancing threshold become flatter for lower attention rates.

[13] See Table 1 for summary statistics of the sample of Danish households with FRMs used in this paper.

Conversely, the bottom panel of Figure 1 plots the optimal refinancing threshold as a function of the attention rate for a household with sample average mortgage characteristics and different short-run discount factors. This figure also demonstrates that present bias increases and inattention decreases the optimal refinancing threshold. In particular, the specification with $\beta = 1$ corresponds to the time-consistent case of exponential discounting and converges to the optimal ADL refinancing threshold as the attention rate increases.[14]

These results can be interpreted as follows. Present-biased households have a strong tendency to defer costs into the future rather than pay them today, even if this is not in favor of their long-run selves. While present-biased households fully value the refinancing costs occurring immediately, potential future savings from refinancing are instantly discounted by the factor β. Consequently, present-biased households are only willing to refinance at higher interest savings and therefore increase their optimal refinancing thresholds compared to otherwise identical households without present bias.

On the other hand, inattentive households consider refinancing only occasionally, for example, on a free weekend or after reading a newspaper article about the current interest rate level. Being aware of their inattention, they are willing to refinance at lower interest savings when a refinancing opportunity arises rather than postponing it to an uncertain future date. As a consequence, they have a lower optimal refinancing threshold compared to fully attentive households that are otherwise identical. Even if these households are also present-biased, they are willing to take advantage of these occasional refinancing opportunities when they arise and therefore reduce their optimal refinancing threshold accordingly. Overall, present bias leads to higher optimal refinancing thresholds, whereas inattention mitigates this effect.

3. Structural estimation

In this section, I present the structural estimation of the behavioral refinancing model and show that present bias and inattention can endogenously explain delays in mortgage refinancing. First, I introduce the Danish household data and the estimation procedure. Then, I present the results of the estimation and examine the robustness of the results.

3.1. Data

I examine the refinancing behavior of households with FRMs based on Danish administrative data between 2009 and 2017.[15] The Danish mortgage system provides

[14] See Appendix B for boundary cases of the optimal refinancing threshold.

[15] I use the same dataset as Andersen et al. (2020).

a unique framework to investigate the refinancing decisions of households.[16] In Denmark, FRMs are common mortgage contracts that households can refinance at the current market yield without penalty. In particular, all households are eligible to refinance their mortgage, regardless of their credit quality or other financial constraints, provided that it is not a cash-out refinancing in which they convert home equity into cash. Even if households do not have enough liquid financial assets to cover the refinancing costs, they can increase the loan amount by those costs without it being classified as cash-out refinancing. The high quality of the Danish administrative data also allows linking household information to mortgage information over the entire life of the loan.

I derive the data from four Danish administrative registers through Statistics Denmark, covering the entire Danish population. The mortgage data are from Danmarks Nationalbank, the demographic data are from the Danish Civil Registration System, the income and wealth data from Danish Tax authorities, and the educational data from the Danish Ministry of Education. A unique personal identification number is used to link these annual data.

The sample selection is based on the procedure of Andersen et al. (2020). Accordingly, I treat one or two adults with the same address as a household. In order to accurately link households to mortgages, I consider only those households each year whose number of adults remains unchanged in the following year. Also, I restrict the analysis to households with a single FRM in the current year and a single mortgage in the following year, leaving 2,414,299 yearly household observations. Finally, using the mortgage origination dates, I expand the annual data to quarterly data, resulting in 9,323,871 quarterly household observations. Table 1 provides summary statistics of the sample.[17]

3.2. Maximum likelihood procedure

I estimate the behavioral refinancing model using maximum likelihood and the described Danish household data. For a household i, it is optimal to refinance in quarter t, when the refinancing incentive I^*_{it} given by

$$I^*_{it} = (m_{it} - i_{it}) - x^*_{it}$$

is positive, where m_{it} is the nominal mortgage rate of the original contract, i_{it} is the nominal mortgage rate of a potential new contract determined by the current market yield, and x^*_{it} is the absolute value of the optimal refinancing threshold from Section 2, which depends on the parameters of the refinancing model.

For the ADL parameters, I employ the values suggested in Andersen et al. (2020)

[16] See Andersen et al. (2020) for a detailed description of the Danish mortgage system.
[17] See Table 3 in Appendix C for summary statistics at the household level.

Table 1: Summary statistics.

	Refinancing quarters	All quarters
Household characteristics		
Age	49.305	52.145
Length of education	15.078	14.704
Income	0.690	0.632
Financial wealth	0.006	0.074
Housing wealth	1.763	1.633
Single male household	0.097	0.128
Single female household	0.101	0.123
Married household	0.659	0.626
Children in family	0.484	0.409
Immigrant	0.079	0.080
Financially literate	0.070	0.056
Family financially literate	0.190	0.162
Getting married	0.015	0.010
Having children	0.061	0.043
Region of Northern Jutland	0.123	0.127
Region of Middle Jutland	0.248	0.239
Region of Southern Denmark	0.219	0.232
Region of Zealand	0.166	0.183
Region of Copenhagen	0.244	0.219
Mortgage characteristics		
Remaining principal	1.176	0.983
Remaining loan term	24.457	23.231
Loan-to-value (LTV) ratio	0.656	0.600
Refinancing	1.000	0.041
Observations	377,891	9,323,871

This table reports the average household and mortgage characteristics of the sample of Danish households with FRMs. The first column refers to refinancing quarters and the second column to all quarters. Income, financial wealth, housing wealth, and remaining principal are given in millions of Danish kroner (DKK) and age, length of education, and remaining loan term in years. The remaining variables, except for the loan-to-value (LTV) ratio, are indicator variables that can take the values 0 or 1.

for the Danish context. That is, I use a mortgage rate volatility of $\sigma = 0.0074$, a marginal tax rate of $\tau = 0.33$, and a long-run discount rate of $\rho = 0.05$.[18] Furthermore, I choose refinancing costs of the form $C(M_{it}) = \frac{\kappa(M_{it})}{1-\tau}$ with

$$\kappa(M_{it}) = 3{,}000 + \max(0.002M_{it}, 4{,}000) + 0.001M_{it}\,,$$

where M_{it} is the mortgage value. The expected real rate of exogenous mortgage repayment λ_{it} is specified by

$$\lambda_{it} = \mu_{it} + \frac{m_{it}}{\exp(m_{it}\Gamma_{it}) - 1} + \pi_t\,,$$

[18] Due to a parameter identification problem, it is not possible to simultaneously estimate the long-run discount rate ρ and the short-run discount factor β from the data. Therefore, I employ the value $\rho = 0.05$, which is commonly used in the literature on mortgage refinancing (see, e.g., Agarwal et al., 2016; Keys et al., 2016; Andersen et al., 2020).

where μ_{it} is the exogenous mortgage termination rate, Γ_{it} is the remaining loan term, and π_t the inflation rate. I estimate μ_{it} in a separate regression using additional data on loan termination apart from refinancing. To be more precise, I estimate the logit model

$$\mu_{it} = \mathbb{P}(\text{Termination}) = \mathbb{P}(\boldsymbol{\mu}'\boldsymbol{z}_{it} + \epsilon_{it} > 0)\,,$$

where $\boldsymbol{\mu}$ is a parameter vector, $\boldsymbol{z}_{it}$ is a vector of mortgage and household characteristics, and ϵ_{it} is a standard logistic distributed random variable. Moreover, I calculate the inflation rate π_t in quarter t based on the consumer price index change in Denmark over the past year.

The variables of interest, the short-run discount factor β_{it} and the attention rate γ_{it}, are modeled as functions of the mortgage and household characteristics. I set $\beta_{it} = \frac{\exp(\boldsymbol{\varphi}'\boldsymbol{z}_{it})}{1+\exp(\boldsymbol{\varphi}'\boldsymbol{z}_{it})}$ and $\gamma_{it} = \exp(\boldsymbol{\chi}'\boldsymbol{z}_{it})$, where $\boldsymbol{z}_{it}$ is a vector of mortgage and household characteristics, and $\boldsymbol{\varphi}$ and $\boldsymbol{\chi}$ are parameter vectors. The attention rate γ_{it} corresponds to the probability $w_{it} = 1 - e^{-\gamma_{it}3/12}$ that household i is attentive in quarter t.

Because there may be deviations from the optimal refinancing rule given by the model, I assume that household i refinances with probability w_{it} in quarter t when

$$\exp(\alpha) I^*(\boldsymbol{z}_{it}; \boldsymbol{\varphi}, \boldsymbol{\chi}) + \epsilon_{it} > 0\,,$$

with refinancing incentive $I^*(\boldsymbol{z}_{it}; \boldsymbol{\varphi}, \boldsymbol{\chi}) = I^*_{it}$, scalar parameter α, and standard logistic distributed stochastic choice error ϵ_{it}, see Andersen et al. (2020). Accordingly, the likelihood contribution of household i in quarter t is

$$\mathcal{L}_{it}(\alpha, \boldsymbol{\varphi}, \boldsymbol{\chi}) = \begin{cases} w_{it}\Lambda(\exp(\alpha) I^*(\boldsymbol{z}_{it}; \boldsymbol{\varphi}, \boldsymbol{\chi}))\,, & y_{it} = 1\,, \\ 1 - w_{it}\Lambda(\exp(\alpha) I^*(\boldsymbol{z}_{it}; \boldsymbol{\varphi}, \boldsymbol{\chi}))\,, & y_{it} = 0\,, \end{cases}$$

where $y_{it} = 1$ indicates that household i refinances in quarter t, and Λ is the inverse logistic function given by $\Lambda(x) = \exp(x)/(1 + \exp(x))$. Overall, the log-likelihood function is

$$\ln \mathcal{L}(\alpha, \boldsymbol{\varphi}, \boldsymbol{\chi}) = \sum_i \sum_t \ln \mathcal{L}_{it}(\alpha, \boldsymbol{\varphi}, \boldsymbol{\chi})\,,$$

which depends on the scalar parameter α and the parameter vectors $\boldsymbol{\varphi}$ and $\boldsymbol{\chi}$.

3.3. Results

Using the maximum likelihood procedure described above, I estimate the behavioral refinancing model. This approach provides estimates for the short-run discount

Table 2: Maximum likelihood estimates.

	α	φ	χ
Intercept	0.723 (0.005)	0.189 (0.011)	−3.141 (0.025)
Rank of:			
Age		−0.579 (0.009)	−0.787 (0.013)
Length of education		0.103 (0.008)	0.215 (0.010)
Income		−0.305 (0.010)	0.409 (0.015)
Financial wealth		−0.369 (0.007)	−0.136 (0.010)
Housing wealth		0.042 (0.008)	0.728 (0.012)
Single male household		−0.064 (0.008)	−0.087 (0.011)
Single female household		−0.005 (0.008)	0.045 (0.011)
Married household		−0.076 (0.006)	0.006 (0.008)
Children in family		−0.219 (0.005)	−0.099 (0.007)
Immigrant		−0.060 (0.007)	−0.086 (0.010)
Financially literate		0.091 (0.009)	0.056 (0.012)
Family financially literate		0.054 (0.006)	0.062 (0.008)
Getting married		0.168 (0.018)	0.142 (0.024)
Having children		0.184 (0.009)	0.108 (0.012)
Region of Northern Jutland		0.114 (0.007)	0.054 (0.009)
Region of Middle Jutland		0.082 (0.005)	0.041 (0.008)
Region of Southern Denmark		0.052 (0.006)	−0.032 (0.008)
Region of Zealand		−0.097 (0.006)	−0.180 (0.009)
Current quarter dummies		Yes	
Mortgage age dummies		Yes	
Observations		9,323,871	

This table reports the maximum likelihood estimates of the empirical specification of the behavioral refinancing model. The first column refers to the estimate of the parameter α capturing the responsiveness of households to the refinancing incentive given by the behavioral refinancing model. The second column refers to the estimate of the parameter vector φ capturing the present bias of households. Finally, the third column refers to the estimate of the parameter vector χ capturing the inattention of households. The parameter vectors φ and χ depend on the household characteristics listed in the rows. Standard errors are reported in parentheses.

factor and the attention rate based on household characteristics. Table 2 reports the results. Almost all coefficients are statistically significant at least at the 1 percent level.[19]

Examination of the results shows that most household characteristics have the same effect on both behavioral biases; that is, an increase in most of these variables can be associated with either more or less rational behavior of households.[20] Older households are more present-biased and more inattentive, while better educated households are less present-biased and less inattentive. One possible explanation

[19] Only the present bias coefficient for the dummy variable single female household and the inattention coefficient for the dummy variable married household are close to zero and not significant.

[20] This work categorizes both present bias and inattention as behavioral biases, as they are deviations from classical economic assumptions of rational decision-making. While present bias reflects a clear preference for immediate rewards, inattention could be partially rationalized by constraints like limited time or cognitive resources.

for these results is that higher cognitive abilities, which may be more prevalent among younger or better-educated households, result in fewer behavioral biases.[21] Moreover, financial literacy of the household or the family of the household reduces both behavioral biases.

Financially wealthier households are more present-biased and inattentive, while higher housing wealth has the opposite effect. Hence, households for which the house constitutes a significant fraction of their wealth and is therefore more important to them exhibit fewer behavioral biases.[22] Higher-income households are more present-biased but also pay more attention to mortgage rates. In other words, higher-income households seem to be more aware of their refinancing option and react more quickly when the mortgage rate reaches their desired level. However, they are also more present-biased when trading off between the costs and benefits of refinancing, possibly due to stress or cognitive overload.

The life events of getting married or having children reduce the two behavioral biases, potentially because they cause households to become more concerned with their financial situation. On the other hand, households with children make more mistakes, which could possibly be explained by a lack of time or distraction. Finally, also immigrants exhibit more behavioral biases.[23]

Figure 2 illustrates the estimated cross-sectional distribution of present bias and inattention. The top panel of Figure 2 shows the estimated distribution of the short-run discount factor. The estimated short-run discount factor ranges from about 0.2 to about 0.6 with a mean of 0.39 and a standard deviation of 0.06, indicating a substantial degree of present bias. In comparison, Laibson et al. (2020) find a similar level of present bias in the US with a short-run discount factor of 0.5.

The bottom panel of Figure 2 shows the estimated distribution of the attention rate in a representative quarter of the sample by using an average mortgage age and an average quarter-time effect, following the approach employed by (Andersen et al., 2020).[24] The estimated attention rate varies between about 0.1 and 1.6 with a mean of 0.44 and a standard deviation of 0.19. This implies that the average household considers refinancing only with a probability of 10% in a typical quarter.

The correlation between the estimated short-run discount factor and the estimated attention rate is 0.25, indicating that the two behavioral biases are weakly positively correlated. Hence, there is a certain positive relationship between present bias and

[21] For example, Frederick (2005) and Benjamin et al. (2013) show that higher cognitive abilities reduce behavioral biases.

[22] Similarly, Agarwal et al. (2016) show that US households for which the mortgage is more important, measured by the ratio of the mortgage value to the income, make smaller refinancing mistakes.

[23] Consistent with this result, Bajo and Barbi (2018) find that immigrants in Italy are less likely to take advantage of favorable refinancing opportunities.

[24] Here, I consider a representative quarter to get a smoother distribution of attention among Danish households. However, there is also a strong time variation in the attention of households to mortgage rates, see Andersen et al. (2020).

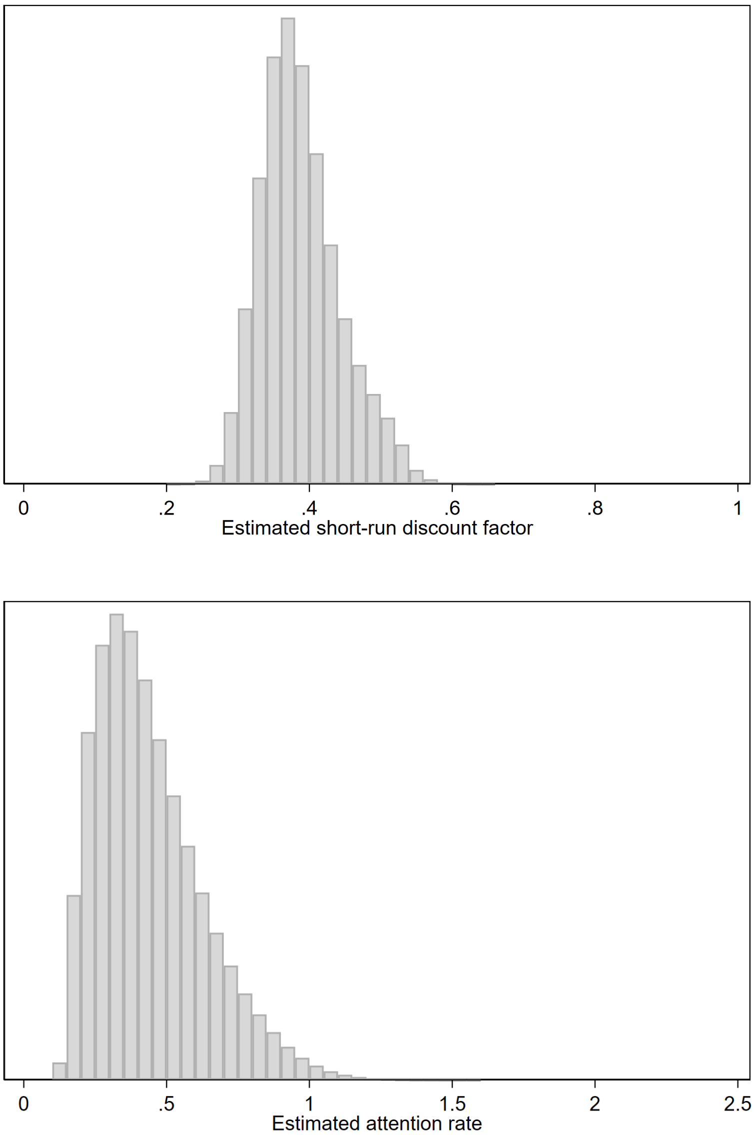


Figure 2: Behavioral biases. This figure illustrates the estimated cross-sectional distribution of present bias and inattention. The top plot shows a histogram of the estimated short-run discount factor. The bottom plot shows a histogram of the estimated attention rate, calculated in a representative quarter by using the average mortgage age and average quarter-time effect.

inattention among households. As discussed above, most household characteristics have the same effect on the two behavioral biases.

Figure 3 compares the estimated optimal refinancing threshold given by the behavioral refinancing model and the corresponding optimal refinancing threshold given by the fully rational ADL model. The top plot of Figure 3 shows the estimated distribution of the behavioral refinancing threshold and the distribution of the ADL refinancing threshold. The estimated behavioral refinancing threshold has a mean of 116 basis points and a standard deviation of 84 basis points. In contrast, the ADL threshold averages 81 basis points with a standard deviation of 28 basis points. Hence, the distribution of the behavioral refinancing threshold is higher on average

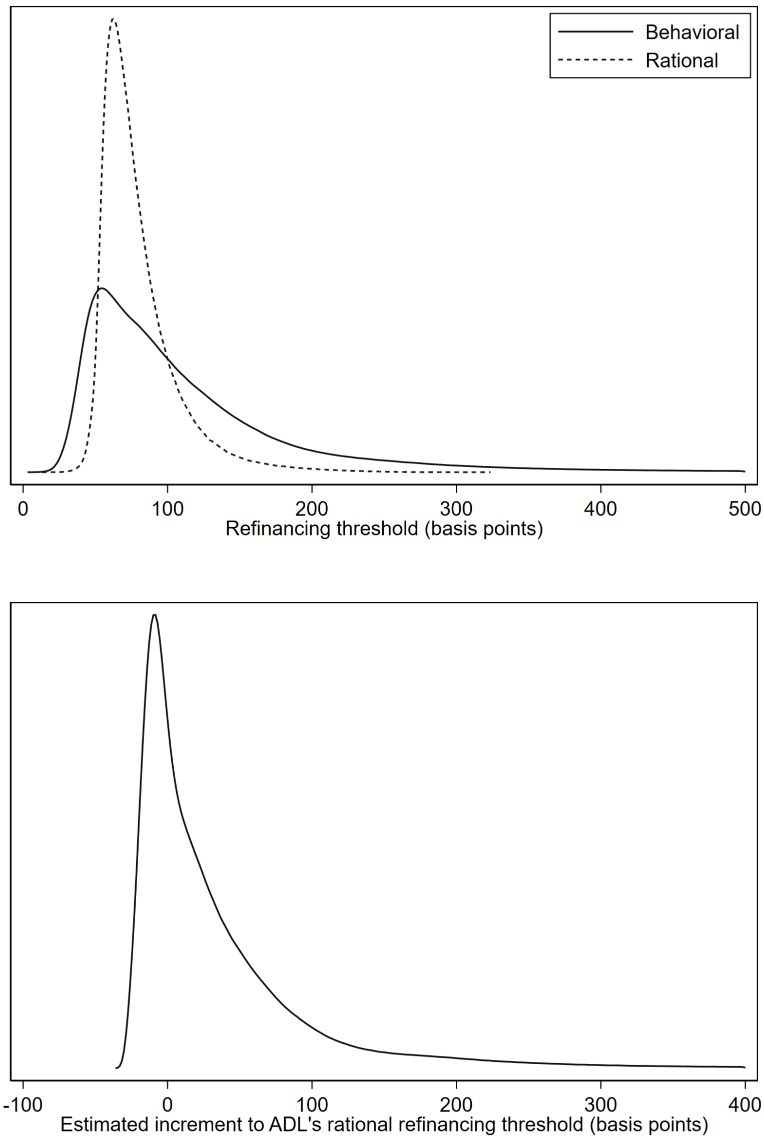


Figure 3: Behavioral refinancing threshold and ADL's rational counterpart. This figure compares the estimated optimal refinancing threshold given by the behavioral model with the optimal refinancing threshold given by the fully rational ADL model. The top plot shows the distribution of the estimated behavioral refinancing threshold (solid) and the distribution of the corresponding ADL refinancing threshold (short-dashed). The bottom plot shows the distribution of the difference between the behavioral refinancing threshold and the ADL refinancing threshold.

compared to ADL's rational counterpart and is also more dispersed. Households that are predominantly present-biased stretch the distribution of the estimated behavioral refinancing threshold to the right, while predominantly inattentive households cause the opposite effect.

The bottom plot of Figure 3 shows the distribution of the difference between the estimated behavioral refinancing threshold and the ADL refinancing threshold. The difference of the two refinancing thresholds has a mean of 35 basis points and a standard deviation of 65 basis points. Hence, for most households, the effect of present bias predominates and leads to a higher estimated behavioral refinancing thresh-

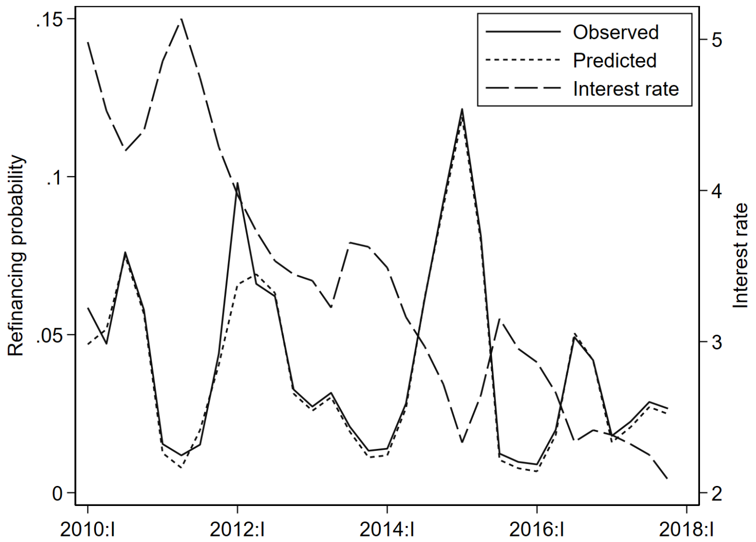


Figure 4: Observed and predicted refinancing probabilities. This figure illustrates the evolution of observed refinancing probabilities (solid), predicted refinancing probabilities by the behavioral refinancing model (short-dashed), and Danish mortgage interest rates (long-dashed) over the period from 2010 to 2017.

old compared to the corresponding ADL threshold. However, for some households, the effect of inattention is predominant and leads to a smaller estimated behavioral threshold.

Given the mortgage characteristics, time preferences, and level of inattention of a household, as well as the current mortgage interest rate, the behavioral refinancing model predicts the probability of a household to refinance. Figure 4 shows the evolution of observed and predicted refinancing probabilities between 2010 and 2017 and the corresponding Danish mortgage interest rates. The figure and the associated R^2 of 94% highlight that the predictions of the behavioral refinancing model with present bias and inattention can closely match the observed refinancing behavior.

3.4. Robustness

This subsection aims to test the robustness of the empirical results to changes in the assumed model parameters. To this end, I re-estimate the model using alternative values for the long-run discount rate, the mortgage rate volatility, and the exogenous mortgage termination rate.[25]

In Appendix D, I decrease the long-run discount rate to $\rho = 0.01$, consistent with the estimate provided by Laibson et al. (2020) for the US. Despite this change, the signs of the estimates remain consistent with the original analysis. However, the lower long-run discount rate leads to a stronger present bias, with an average short-run discount factor of $\beta = 0.35$. In Appendix E, I increase the long-run discount rate to $\rho = 0.09$, which still results in consistent signs of the estimates,

25 Andersen et al. (2020) conduct similar robustness checks.

but with a higher average short-run discount factor of $\beta = 0.42$. Therefore, the specifications with alternative long-run discount rates alter the distribution of the short-run discount factor but still indicate significant present bias and lead to similar conclusions regarding the effects of household characteristics on behavioral biases.

In Appendix F, I use a lower mortgage rate volatility of $\sigma = 0.0037$, which is half of the original volatility used in the main analysis. The change in volatility decreases ADL's fully rational refinancing threshold by approximately 20 basis points on average, but otherwise, the results remain largely robust to this change. Finally, in Appendix G, I examine a fixed exogenous mortgage termination rate of $\mu_{it} = 0.1$. The change of the exogenous mortgage termination rate decreases the dispersion of the estimated short-run discount factor and slightly compromises the model's fit; however, apart from these effects, the change does not have a major impact on the robustness of the results.

4. Conclusion

This paper examines whether and to what extent present bias causes delays in mortgage refinancing. To address this open question, I study the mortgage refinancing problem of a behavioral household that is present-biased and inattentive to mortgage rates. In solving the problem, I derive the first closed-form optimal refinancing rule of a behavioral household, enabling the estimation of the model. I estimate the model based on Danish administrative data, showing that the model can endogenously explain delays in mortgage refinancing. In addition, I find substantial evidence of present bias among households, with the average household having a short-run discount factor of $\beta = 0.39$. Older, less-educated, financially wealthier, and higher-income households exhibit stronger present bias, whereas higher housing wealth and financial literacy reduce this behavioral bias.

The results have implications for the transmission of monetary policy. The empirical findings suggest that present bias is a major driver for delays in refinancing and therefore should be taken into account when considering the refinancing channel of monetary policy. Hence, the empirical results support the theoretical macroeconomic model with present bias and refinancing recently proposed by Laibson et al. (2021), and complement it with new insights into the extent and distribution of present bias among households with FRMs. The results also suggest cross-sectional differences in response to interest rate cuts, shedding new light on the distributional consequences of monetary policy that are currently discussed by policymakers (see, e.g., Daly, 2020; Feiveson et al., 2020).

Appendix A Proof

Proof of Proposition 2.1. Based on arguments from Harris and Laibson (2013) and standard arguments from stochastic control, the stationary Markov-perfect equilibrium of the IG household is characterized by $V = \beta V_C$, the differential equation

$$\begin{aligned}\rho V_C(x,r) =& (-x+r)M + \frac{\sigma^2}{2}\frac{\partial^2 V_C}{\partial x^2}(x,r) + \lambda(M - V_C(x,r)) \\ &+ \mathbb{1}_{x\le x^*}\gamma(V_C(0,r) + C(M) - V_C(x,r))\,,\end{aligned} \tag{A.1}$$

the value-matching condition

$$\beta V_C(x^*,r) = \beta V_C(0,r) + C(M)\,, \tag{A.2}$$

and further appropriate boundary conditions, where x^* is the optimal refinancing threshold.[26] Here, V_C is the continuation value function, representing the expected present discounted value of the household's real mortgage payments, exponentially discounted at rate ρ. Analogous to the representation of the value function in ADL, I express the continuation value function V_C as

$$V_C(x,r) = \frac{(-x+r+\lambda)M}{\rho+\lambda} - R_C(x)\,, \tag{A.3}$$

where the first term on the right-hand side of the equation in (A.3) corresponds to the expected present discounted value of future mortgage payments conditional on not refinancing, and the function R_C to the option value of refinancing, using exponential discounting at rate ρ. By substituting (A.3) into (A.1), I obtain

$$(\rho+\lambda)R_C(x) + \mathbb{1}_{x\le x^*}\gamma\left(R_C(x) - R_C(0) + C(M) + \frac{xM}{\rho+\lambda}\right) = \frac{\sigma^2}{2}R_C''(x)\,. \tag{A.4}$$

To solve (A.4), I apply the value-matching condition (A.2). According to (A.3), this condition is equivalent to $R_C(x^*) = R_C(0) - \frac{C(M)}{\beta} - \frac{x^*M}{\rho+\lambda}$. In addition, I exploit value-matching and smooth fit conditions of the value function V at the optimal refinancing threshold x^*. I also use the boundary condition $x^* \le 0$, since optimal refinancing does not increase the mortgage rate. Moreover, I use the boundary condition $\lim_{x\to\infty} R_C(x) = 0$, as the refinancing option loses its value as the interest rate differential gets arbitrarily large. Finally, I exploit that for arbitrarily large negative interest rate differentials, refinancing occurs almost surely at the next opportunity,

[26] Note that (A.1) corresponds to the differential equation of the value function in the case of an exponential discount function with discount rate ρ and otherwise identical model parameters. The value-matching condition in (A.2) is equivalent to $V(x^*,r) = V(0,r) + C(M)$, that is, links the value function V the instant before and after refinancing at x^*.

and hence the option value of refinancing gets linear, where (A.4) implies

$$\lim_{x \to -\infty} R'_C(x) = \frac{\gamma M}{(\rho + \lambda)(\rho + \lambda + \gamma)} \,. \tag{A.5}$$

For $x > x^*$, (A.4) has a solution of the form $R_{C0}(x) = K_0^+ e^{\psi_0 x} + K_0^- e^{-\psi_0 x}$ with $\psi_0 = \frac{\sqrt{2(\rho+\lambda)}}{\sigma}$. The boundary condition $\lim_{x\to\infty} R_C(x) = 0$ implies $K_0^+ = 0$ because otherwise $R_C(x)$ would converge to infinity for $x \to \infty$. For $x \leq x^*$, (A.4) has a solution of the form $R_1(x) = K_1^+ e^{\psi_1 x} + K_1^- e^{-\psi_1 x} - \frac{\gamma M x}{(\rho+\lambda)(\rho+\lambda+\gamma)} - \frac{\gamma(C(M)-R_C(0))}{\rho+\lambda+\gamma}$ with $\psi_1 = \frac{\sqrt{2(\rho+\lambda+\gamma)}}{\sigma}$. Here the boundary condition in (A.5) implies $K_1^- = 0$. Let $K_0 = K_0^-$ and $K_1 = K_1^+$. The boundary condition $x^* \leq 0$ and the value-matching condition in the case $x^* = 0$ give $R_C(0) = R_{C0}(0) = K_0$. Consequently, I get for (A.4) a solution of the form

$$R_C(x) = \begin{cases} K_1 e^{\psi_1 x} - \frac{\gamma M x}{(\rho+\lambda)(\rho+\lambda+\gamma)} - \frac{\gamma(C(M)-K_0)}{\rho+\lambda+\gamma}, & x \leq x^* \,, \\ K_0 e^{-\psi_0 x}, & x > x^* \,. \end{cases} \tag{A.6}$$

By using the value-matching and smooth fit conditions, I obtain for the remaining unknown variables K_0, K_1, and x^* the equations

$$\begin{aligned} K_0 e^{-\psi_0 x^*} &= K_0 - \frac{C(M)}{\beta} - \frac{x^* M}{\rho + \lambda} \,, \\ K_1 e^{\psi_1 x^*} - \frac{\gamma M x^*}{(\rho+\lambda)(\rho+\lambda+\gamma)} - \frac{\gamma(C(M) - K_0)}{\rho + \lambda + \gamma} &= K_0 - \frac{C(M)}{\beta} - \frac{x^* M}{\rho + \lambda} \,, \\ -\psi_0 K_0 e^{-\psi_0 x^*} &= \psi_1 K_1 e^{\psi_1 x^*} - \frac{\gamma M}{(\rho+\lambda)(\rho+\lambda+\gamma)} \,. \end{aligned}$$

These equations imply that K_0, K_1, and x^* are given by (2.3) and (2.4). Moreover, it follows from (A.3) and (A.6) that $V = \beta V_C$ with V_C given by (2.2) is the value function. In particular, refinancing is optimal when $x \leq x^*$, that is, the optimal refinancing policy is given by $\xi_t^* = \int_{[0,t)} \mathbb{1}_{x_s \leq x^*} \, \mathrm{d}N_s$. □

Appendix B Boundary cases of the optimal refinancing rule

B.1 ADL's fully rational case ($\gamma \to \infty$, $\beta = 1$)

For a fully rational household, refinancing is optimal when the current mortgage interest rate is at least by

$$\frac{1}{\psi}[\phi + W(-\exp(-\phi))]$$

lower than the original mortgage rate of the household, where

$$\phi = 1 + \psi(\rho+\lambda)\frac{C(M)}{M},$$
$$\psi = \frac{\sqrt{2(\rho+\lambda)}}{\sigma}.$$

B.2 Purely present-biased case ($\gamma \to \infty$)

For a present-biased and fully attentive household, refinancing is optimal when the current mortgage interest rate is at least by

$$\frac{1}{\psi}[\phi + W(-\exp(-\phi))]$$

lower than the original mortgage rate of the household, where

$$\phi = 1 + \psi(\rho+\lambda)\frac{C(M)}{\beta M},$$
$$\psi = \frac{\sqrt{2(\rho+\lambda)}}{\sigma}.$$

B.3 Purely inattentive case ($\beta = 1$)

For an inattentive household without present bias, refinancing is optimal when the current mortgage interest rate is at least by

$$\frac{1}{\psi_0}[\phi + W(-\chi\exp(-\phi))]$$

lower than the original mortgage rate of the household, where

$$\phi = \chi + \psi_0(\rho+\lambda)\frac{C(M)}{M}, \qquad \chi = \frac{\gamma\psi_0}{(\rho+\lambda+\gamma)\psi_0 + (\rho+\lambda)\psi_1},$$
$$\psi_0 = \frac{\sqrt{2(\rho+\lambda)}}{\sigma}, \qquad \psi_1 = \frac{\sqrt{2(\rho+\lambda+\gamma)}}{\sigma}.$$

Appendix C   Additional descriptive statistics

Table 3: Household-level summary statistics.

	Refinancers	Nonrefinancers	All
Household characteristics			
Age	47.214	49.753	48.477
Length of education	14.964	14.607	14.786
Income	0.676	0.612	0.644
Financial wealth	−0.026	0.053	0.013
Housing wealth	1.783	1.655	1.719
Single male household	0.105	0.169	0.137
Single female household	0.106	0.142	0.124
Married household	0.616	0.526	0.571
Children in family	0.471	0.378	0.425
Immigrant	0.081	0.088	0.085
Financially literate	0.066	0.055	0.060
Family financially literate	0.179	0.157	0.168
Getting married	0.026	0.020	0.023
Having children	0.077	0.061	0.070
Region of Northern Jutland	0.122	0.127	0.124
Region of Middle Jutland	0.246	0.234	0.240
Region of Southern Denmark	0.222	0.238	0.230
Region of Zealand	0.166	0.174	0.170
Region of Copenhagen	0.244	0.226	0.235
Mortgage characteristics			
Remaining principal	1.163	0.970	1.067
Remaining loan term	25.915	23.871	24.898
Loan-to-value (LTV) ratio	0.650	0.590	0.621
Refinancing	1.000	0.000	0.502
Observations	308,274	305,214	613,488

This table reports average household and mortgage characteristics of the sample of Danish households with FRMs. The values are calculated at the household-level, using the information from the first quarter in which a household appears in the sample. The first column refers to households that refinance their mortgage at least once in the observation period, the second column refers to households that do not refinance their mortgage in the observation period, and the third column refers to all households. Income, financial wealth, housing wealth, and remaining principal are given in millions of DKK and age, length of education, and remaining loan term in years. The remaining variables, except for the LTV ratio, are indicator variables that can take the values 0 or 1.

Appendix D Lower long-run discount rate

Table 4: Maximum likelihood estimates—lower long-run discount rate.

	α	$\boldsymbol{\varphi}$	$\boldsymbol{\chi}$
Intercept	0.696 (0.005)	0.084 (0.010)	−3.216 (0.025)
Rank of:			
Age		−0.653 (0.009)	−0.811 (0.012)
Length of education		0.115 (0.007)	0.215 (0.010)
Income		−0.322 (0.010)	0.409 (0.014)
Financial wealth		−0.365 (0.007)	−0.157 (0.010)
Housing wealth		0.051 (0.008)	0.750 (0.012)
Single male household		−0.060 (0.008)	−0.090 (0.011)
Single female household		−0.003 (0.008)	0.046 (0.011)
Married household		−0.099 (0.005)	0.003 (0.008)
Children in family		−0.238 (0.005)	−0.105 (0.007)
Immigrant		−0.047 (0.007)	−0.085 (0.010)
Financially literate		0.089 (0.008)	0.062 (0.012)
Family financially literate		0.056 (0.005)	0.062 (0.008)
Getting married		0.167 (0.017)	0.147 (0.023)
Having children		0.197 (0.008)	0.115 (0.012)
Region of Northern Jutland		0.101 (0.007)	0.047 (0.009)
Region of Middle Jutland		0.072 (0.005)	0.033 (0.008)
Region of Southern Denmark		0.041 (0.006)	−0.038 (0.008)
Region of Zealand		−0.108 (0.006)	−0.188 (0.008)
Current quarter dummies		Yes	
Mortgage age dummies		Yes	
Observations		9,323,871	

This table reports the maximum likelihood estimates for an alternative empirical specification of the behavioral refinancing model with a lower long-run discount rate of $\rho = 0.01$. The first column refers to the estimate of the parameter α capturing the responsiveness of households to the refinancing incentive given by the behavioral refinancing model. The second column refers to the estimate of the parameter vector $\boldsymbol{\varphi}$ capturing the present bias of households. Finally, the third column refers to the estimate of the parameter vector $\boldsymbol{\chi}$ capturing the inattention of households. The parameter vectors $\boldsymbol{\varphi}$ and $\boldsymbol{\chi}$ depend on the household characteristics listed in the rows. Standard errors are reported in parentheses.

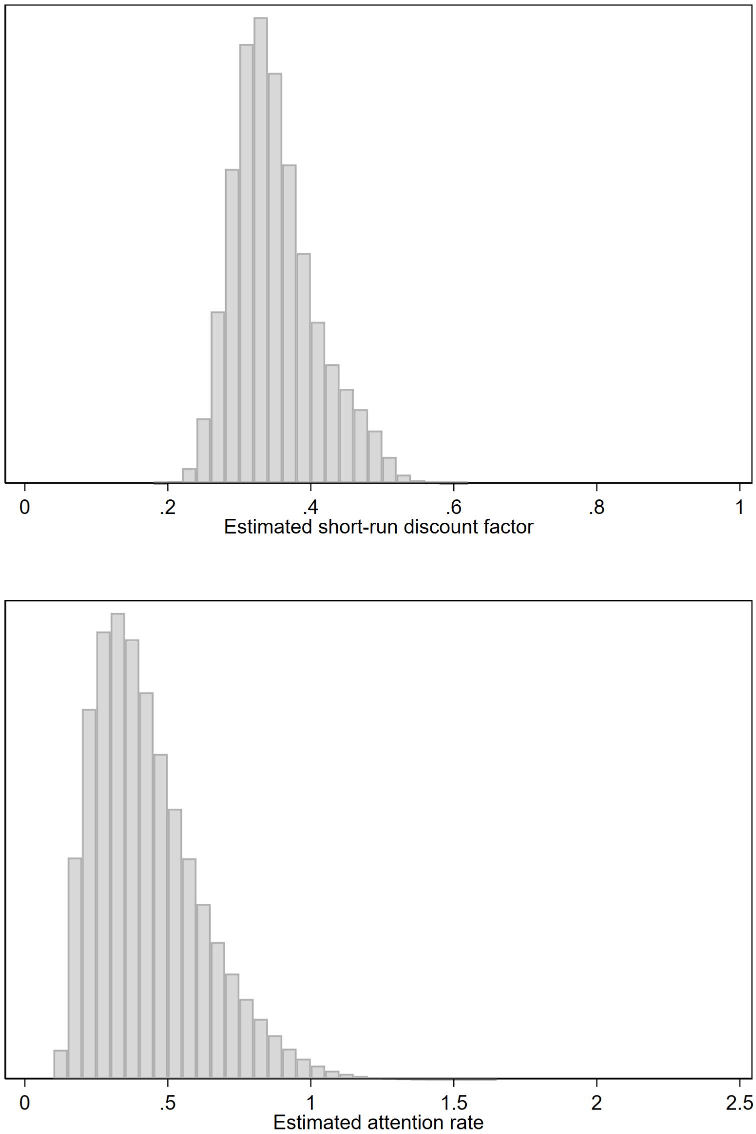


Figure 5: Behavioral biases—lower long-run discount rate. This figure illustrates the estimated cross-sectional distribution of present bias and inattention. The figure is based on the alternative estimates of the model from Table 4. The top plot shows a histogram of the estimated short-run discount factor. The bottom plot shows a histogram of the estimated attention rate, calculated in a representative quarter by using the average mortgage age and average quarter-time effect.

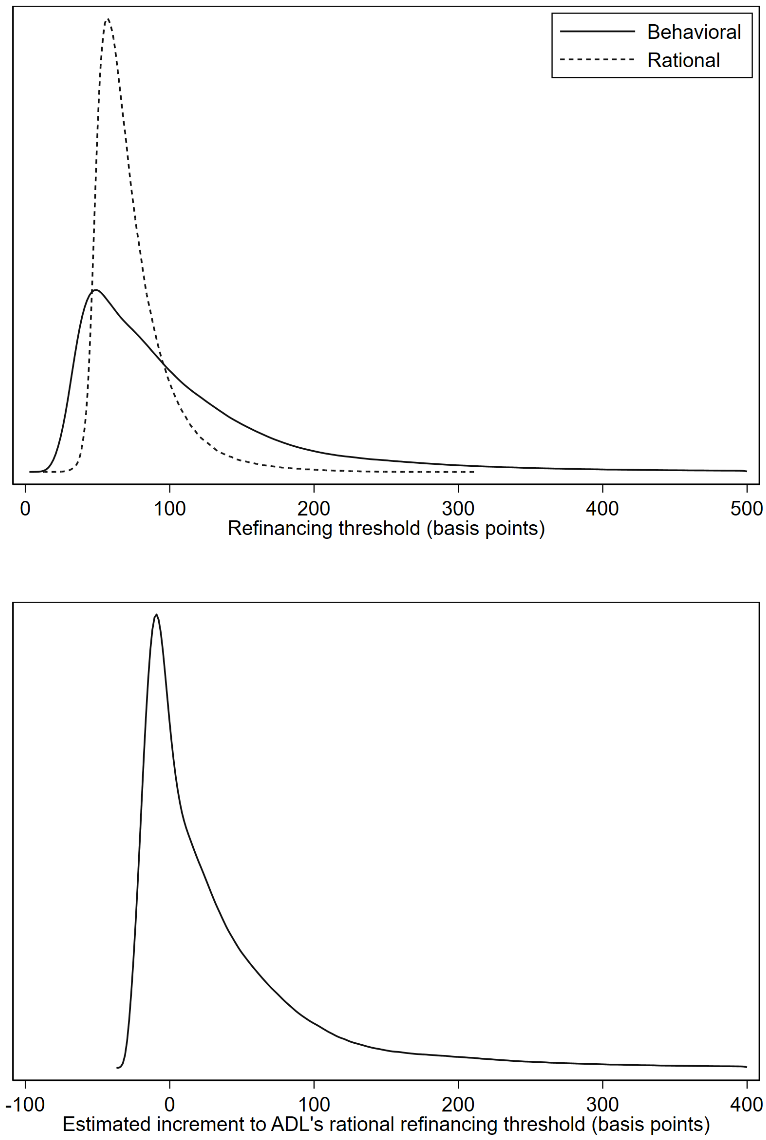


Figure 6: Behavioral refinancing threshold and ADL's rational counterpart—lower long-run discount rate. This figure compares the estimated optimal refinancing threshold given by the behavioral model with the optimal refinancing threshold given by the fully rational ADL model. The figure is based on the alternative estimates of the model from Table 4. The top plot shows the distribution of the estimated behavioral refinancing threshold (solid) and the distribution of the corresponding ADL refinancing threshold (short-dashed). The bottom plot shows the distribution of the difference between the behavioral refinancing threshold and the ADL refinancing threshold.

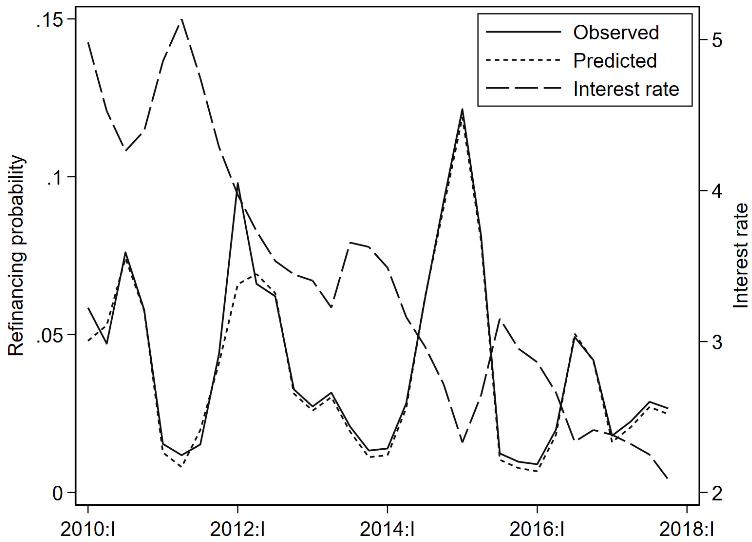


Figure 7: Observed and predicted refinancing probabilities—lower long-run discount rate. This figure illustrates the evolution of observed refinancing probabilities (solid), predicted refinancing probabilities by the behavioral refinancing model (short-dashed), and Danish mortgage interest rates (long-dashed) over the period from 2010 to 2017. The figure is based on the alternative estimates of the model from Table 4.

Appendix E Higher long-run discount rate

Table 5: Maximum likelihood estimates—higher long-run discount rate.

	α	$\boldsymbol{\varphi}$	$\boldsymbol{\chi}$
Intercept	0.737 (0.005)	0.291 (0.011)	−3.074 (0.025)
Rank of:			
Age		−0.526 (0.009)	−0.769 (0.013)
Length of education		0.095 (0.008)	0.215 (0.011)
Income		−0.298 (0.011)	0.407 (0.015)
Financial wealth		−0.372 (0.007)	−0.120 (0.010)
Housing wealth		0.033 (0.009)	0.710 (0.012)
Single male household		−0.068 (0.008)	−0.085 (0.011)
Single female household		−0.006 (0.008)	0.045 (0.011)
Married household		−0.060 (0.006)	0.009 (0.008)
Children in family		−0.207 (0.005)	−0.095 (0.007)
Immigrant		−0.069 (0.007)	−0.087 (0.010)
Financially literate		0.093 (0.009)	0.052 (0.013)
Family financially literate		0.053 (0.006)	0.062 (0.008)
Getting married		0.170 (0.018)	0.138 (0.024)
Having children		0.177 (0.009)	0.103 (0.012)
Region of Northern Jutland		0.123 (0.007)	0.059 (0.010)
Region of Middle Jutland		0.089 (0.005)	0.047 (0.008)
Region of Southern Denmark		0.061 (0.006)	−0.027 (0.008)
Region of Zealand		−0.089 (0.006)	−0.174 (0.009)
Current quarter dummies		Yes	
Mortgage age dummies		Yes	
Observations		9,323,871	

This table reports the maximum likelihood estimates for an alternative empirical specification of the behavioral refinancing model with a higher long-run discount rate of $\rho = 0.09$. The first column refers to the estimate of the parameter α capturing the responsiveness of households to the refinancing incentive given by the behavioral refinancing model. The second column refers to the estimate of the parameter vector $\boldsymbol{\varphi}$ capturing the present bias of households. Finally, the third column refers to the estimate of the parameter vector $\boldsymbol{\chi}$ capturing the inattention of households. The parameter vectors $\boldsymbol{\varphi}$ and $\boldsymbol{\chi}$ depend on the household characteristics listed in the rows. Standard errors are reported in parentheses.

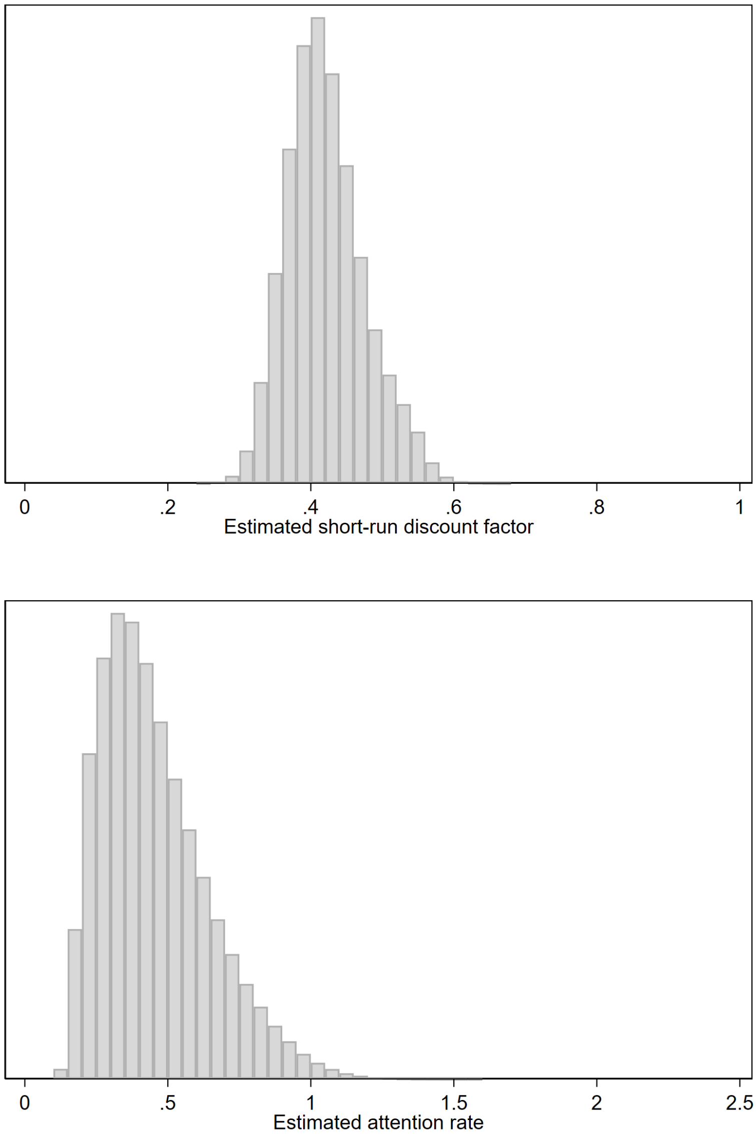
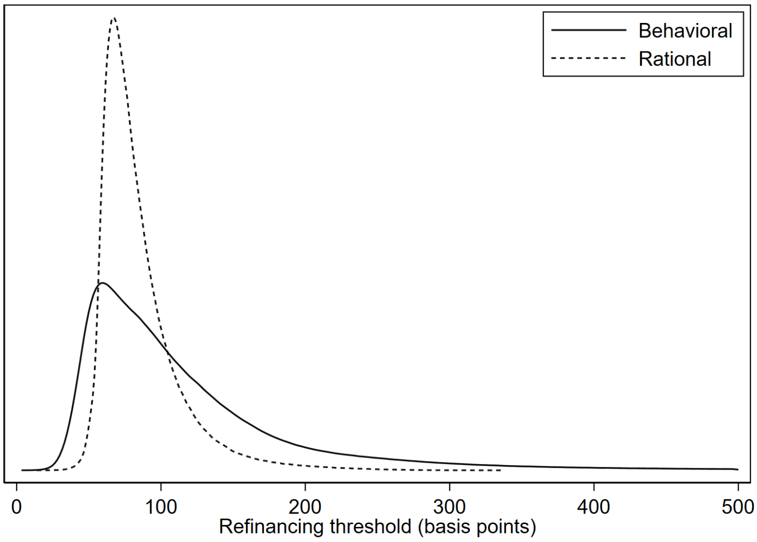


Figure 8: Behavioral biases—higher long-run discount rate. This figure illustrates the estimated cross-sectional distribution of present bias and inattention. The figure is based on the alternative estimates of the model from Table 5. The top plot shows a histogram of the estimated short-run discount factor. The bottom plot shows a histogram of the estimated attention rate, calculated in a representative quarter by using the average mortgage age and average quarter-time effect.



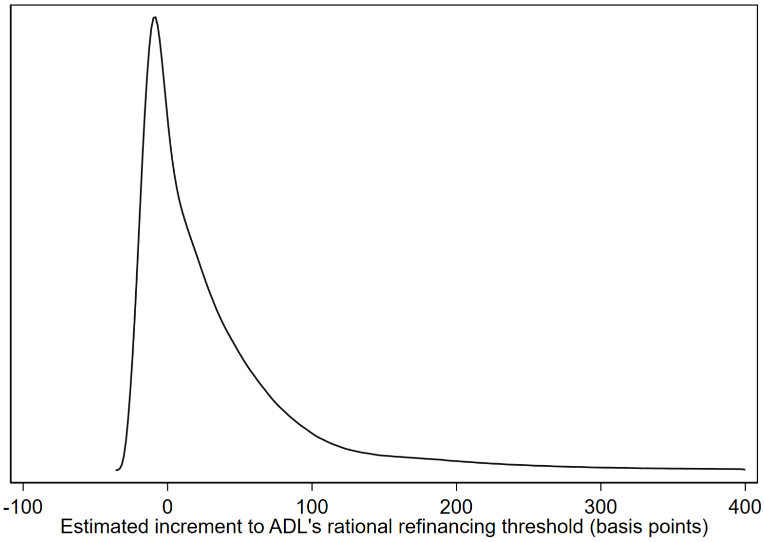


Figure 9: Behavioral refinancing threshold and ADL's rational counterpart—higher long-run discount rate. This figure compares the estimated optimal refinancing threshold given by the behavioral model with the optimal refinancing threshold given by the fully rational ADL model. The figure is based on the alternative estimates of the model from Table 5. The top plot shows the distribution of the estimated behavioral refinancing threshold (solid) and the distribution of the corresponding ADL refinancing threshold (short-dashed). The bottom plot shows the distribution of the difference between the behavioral refinancing threshold and the ADL refinancing threshold.

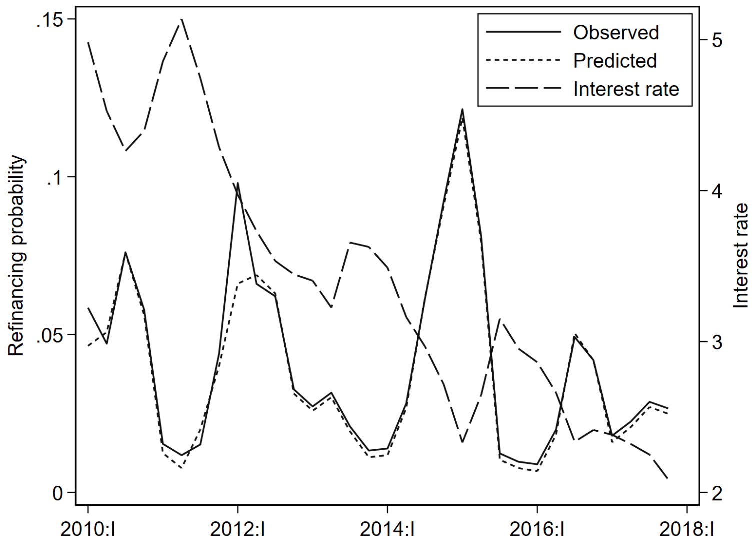


Figure 10: Observed and predicted refinancing probabilities—higher long-run discount rate. This figure illustrates the evolution of observed refinancing probabilities (solid), predicted refinancing probabilities by the behavioral refinancing model (short-dashed), and Danish mortgage interest rates (long-dashed) over the period from 2010 to 2017. The figure is based on the alternative estimates of the model from Table 5.

Appendix F Lower mortgage rate volatility

Table 6: Maximum likelihood estimates—lower mortgage rate volatility.

	α	$\boldsymbol{\varphi}$	$\boldsymbol{\chi}$
Intercept	0.780 (0.005)	0.233 (0.013)	−3.174 (0.025)
Rank of:			
Age		−0.548 (0.010)	−0.764 (0.014)
Length of education		0.084 (0.009)	0.224 (0.011)
Income		−0.387 (0.012)	0.497 (0.016)
Financial wealth		−0.409 (0.008)	−0.083 (0.011)
Housing wealth		0.035 (0.010)	0.725 (0.013)
Single male household		−0.066 (0.010)	−0.082 (0.012)
Single female household		−0.022 (0.010)	0.059 (0.012)
Married household		−0.082 (0.007)	0.021 (0.009)
Children in family		−0.212 (0.006)	−0.094 (0.008)
Immigrant		−0.045 (0.008)	−0.104 (0.011)
Financially literate		0.100 (0.009)	0.043 (0.014)
Family financially literate		0.054 (0.006)	0.059 (0.008)
Getting married		0.175 (0.023)	0.123 (0.027)
Having children		0.178 (0.010)	0.107 (0.013)
Region of Northern Jutland		0.083 (0.008)	0.096 (0.010)
Region of Middle Jutland		0.059 (0.006)	0.072 (0.009)
Region of Southern Denmark		0.031 (0.007)	0.003 (0.009)
Region of Zealand		−0.094 (0.007)	−0.171 (0.009)
Current quarter dummies		Yes	
Mortgage age dummies		Yes	
Observations		9,323,871	

This table reports the maximum likelihood estimates for an alternative empirical specification of the behavioral refinancing model with a lower mortgage rate volatility of $\sigma = 0.0037$. The first column refers to the estimate of the parameter α capturing the responsiveness of households to the refinancing incentive given by the behavioral refinancing model. The second column refers to the estimate of the parameter vector $\boldsymbol{\varphi}$ capturing the present bias of households. Finally, the third column refers to the estimate of the parameter vector $\boldsymbol{\chi}$ capturing the inattention of households. The parameter vectors $\boldsymbol{\varphi}$ and $\boldsymbol{\chi}$ depend on the household characteristics listed in the rows. Standard errors are reported in parentheses.

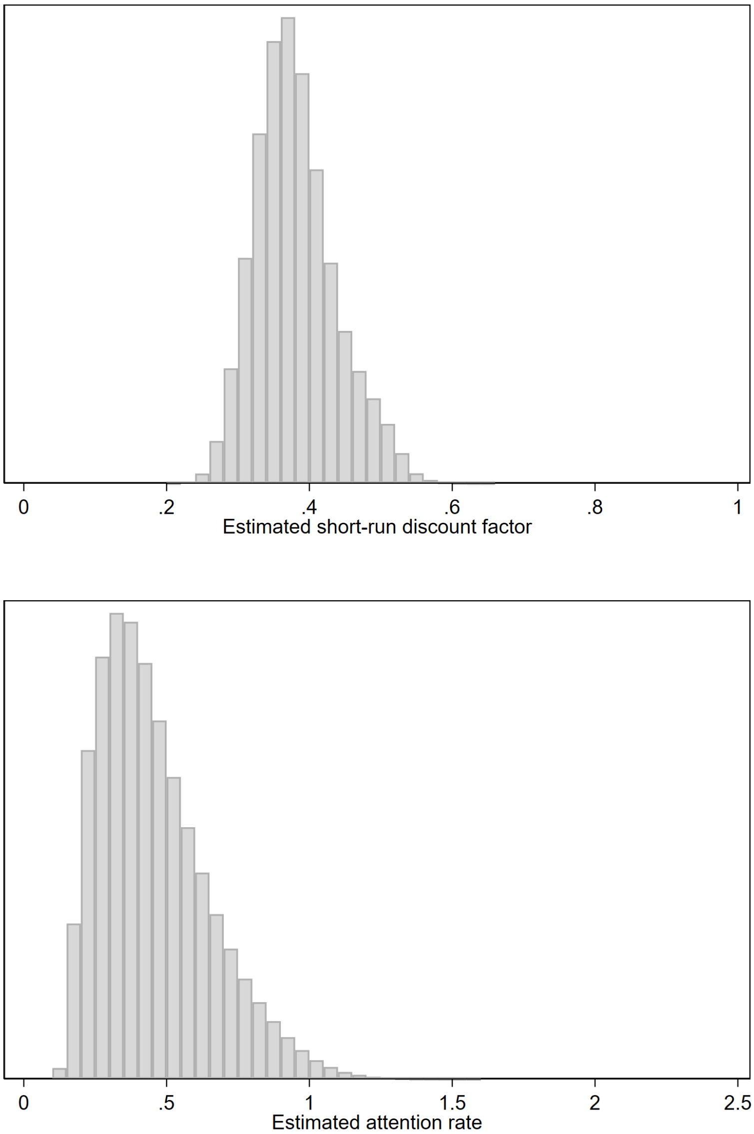
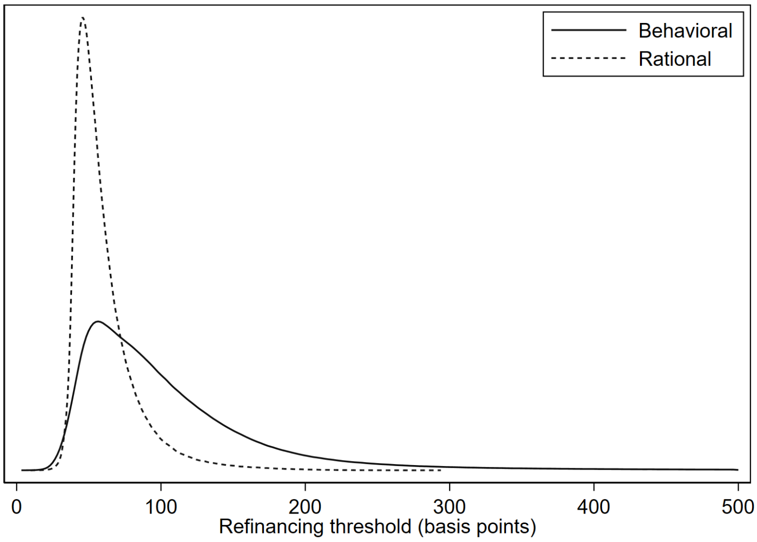


Figure 11: Behavioral biases—lower mortgage rate volatility. This figure illustrates the estimated cross-sectional distribution of present bias and inattention. The figure is based on the alternative estimates of the model from Table 6. The top plot shows a histogram of the estimated short-run discount factor. The bottom plot shows a histogram of the estimated attention rate, calculated in a representative quarter by using the average mortgage age and average quarter-time effect.



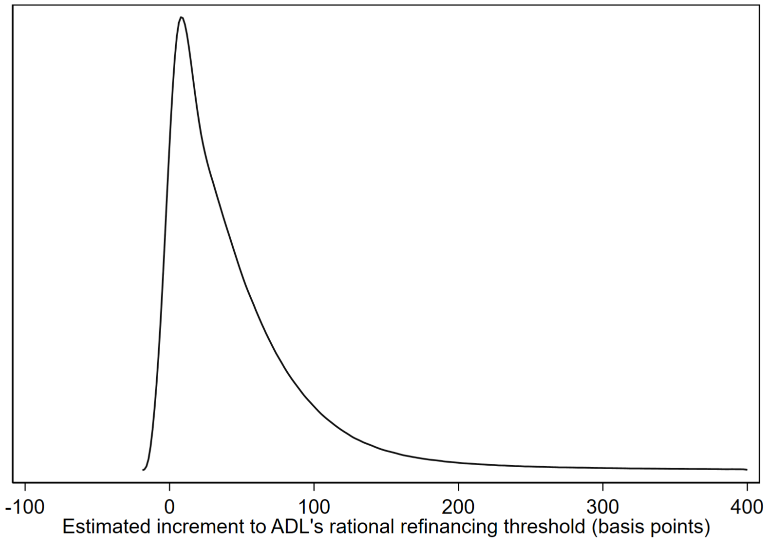


Figure 12: Behavioral refinancing threshold and ADL's rational counterpart—lower mortgage rate volatility. This figure compares the estimated optimal refinancing threshold given by the behavioral model with the optimal refinancing threshold given by the fully rational ADL model. The figure is based on the alternative estimates of the model from Table 6. The top plot shows the distribution of the estimated behavioral refinancing threshold (solid) and the distribution of the corresponding ADL refinancing threshold (short-dashed). The bottom plot shows the distribution of the difference between the behavioral refinancing threshold and the ADL refinancing threshold.

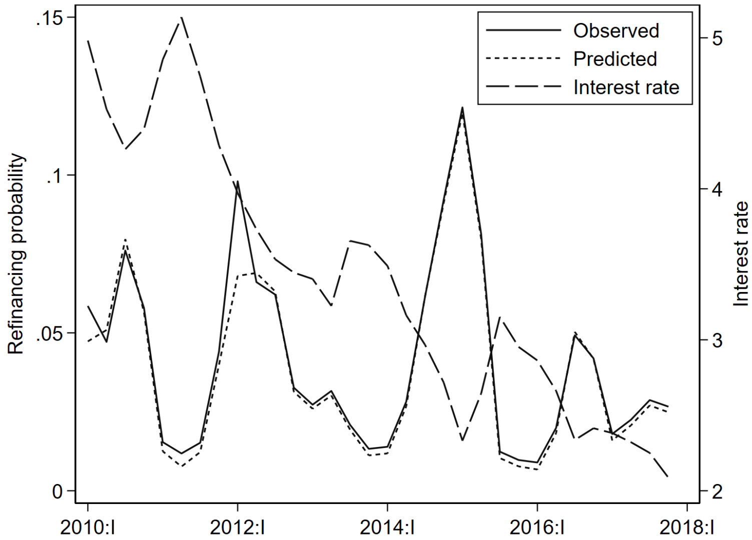


Figure 13: Observed and predicted refinancing probabilities—lower mortgage rate volatility. This figure illustrates the evolution of observed refinancing probabilities (solid), predicted refinancing probabilities by the behavioral refinancing model (short-dashed), and Danish mortgage interest rates (long-dashed) over the period from 2010 to 2017. The figure is based on the alternative estimates of the model from Table 6.

Appendix G Fixed exogenous mortgage termination rate

Table 7: Maximum likelihood estimates—fixed exogenous mortgage termination rate.

	α	$\boldsymbol{\varphi}$	$\boldsymbol{\chi}$
Intercept	1.090 (0.004)	−0.356 (0.009)	−0.667 (0.031)
Rank of:			
Age		−0.071 (0.007)	−0.537 (0.013)
Length of education		0.023 (0.006)	0.193 (0.011)
Income		−0.082 (0.009)	0.507 (0.014)
Financial wealth		−0.250 (0.006)	−0.049 (0.010)
Housing wealth		0.059 (0.007)	0.622 (0.012)
Single male household		−0.057 (0.007)	−0.081 (0.011)
Single female household		0.014 (0.007)	0.071 (0.011)
Married household		0.048 (0.004)	0.098 (0.007)
Children in family		−0.048 (0.004)	−0.046 (0.007)
Immigrant		−0.096 (0.006)	−0.142 (0.010)
Financially literate		0.089 (0.007)	−0.029 (0.013)
Family financially literate		0.033 (0.004)	0.062 (0.008)
Getting married		0.115 (0.012)	0.081 (0.022)
Having children		0.072 (0.006)	0.057 (0.011)
Region of Northern Jutland		0.151 (0.005)	0.151 (0.009)
Region of Middle Jutland		0.109 (0.004)	0.146 (0.008)
Region of Southern Denmark		0.088 (0.005)	0.068 (0.008)
Region of Zealand		−0.047 (0.005)	−0.095 (0.009)
Current quarter dummies		Yes	
Mortgage age dummies		Yes	
Observations		9,323,871	

This table reports the maximum likelihood estimates for an alternative empirical specification of the behavioral refinancing model with a fixed exogenous mortgage termination rate of $\mu_{it} = 0.1$. The first column refers to the estimate of the parameter α capturing the responsiveness of households to the refinancing incentive given by the behavioral refinancing model. The second column refers to the estimate of the parameter vector $\boldsymbol{\varphi}$ capturing the present bias of households. Finally, the third column refers to the estimate of the parameter vector $\boldsymbol{\chi}$ capturing the inattention of households. The parameter vectors $\boldsymbol{\varphi}$ and $\boldsymbol{\chi}$ depend on the household characteristics listed in the rows. Standard errors are reported in parentheses.

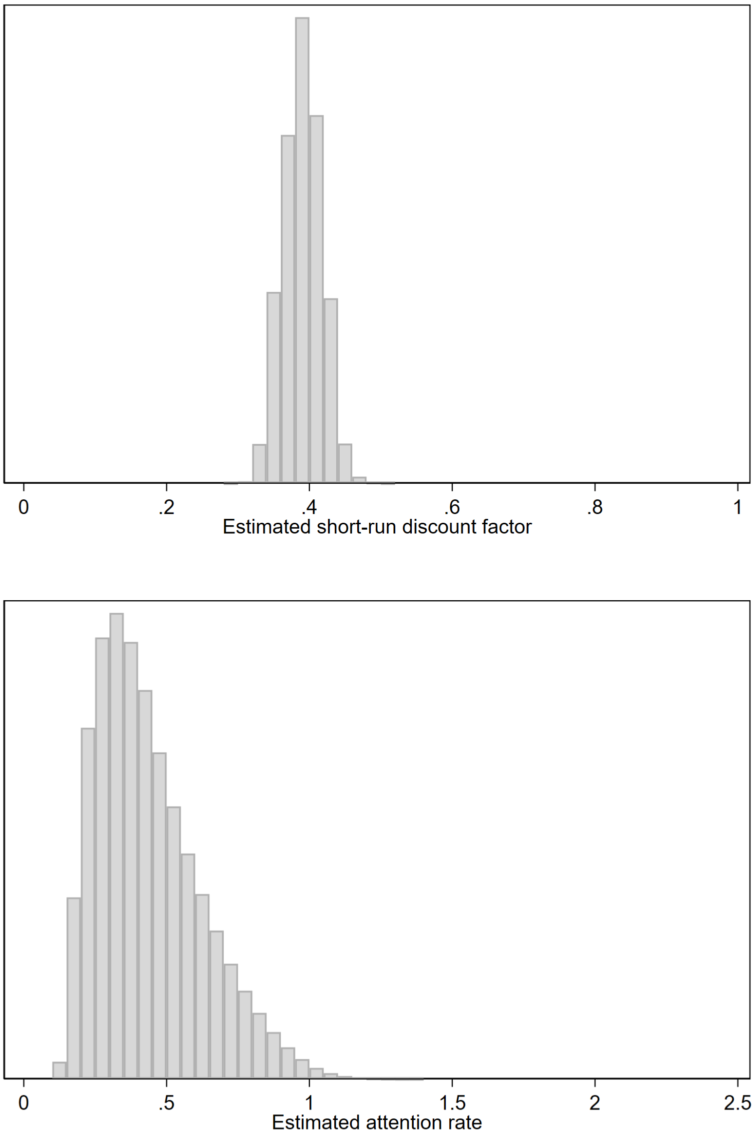


Figure 14: Behavioral biases—fixed exogenous mortgage termination rate. This figure illustrates the estimated cross-sectional distribution of present bias and inattention. The figure is based on the alternative estimates of the model from Table 7. The top plot shows a histogram of the estimated short-run discount factor. The bottom plot shows a histogram of the estimated attention rate, calculated in a representative quarter by using the average mortgage age and average quarter-time effect.

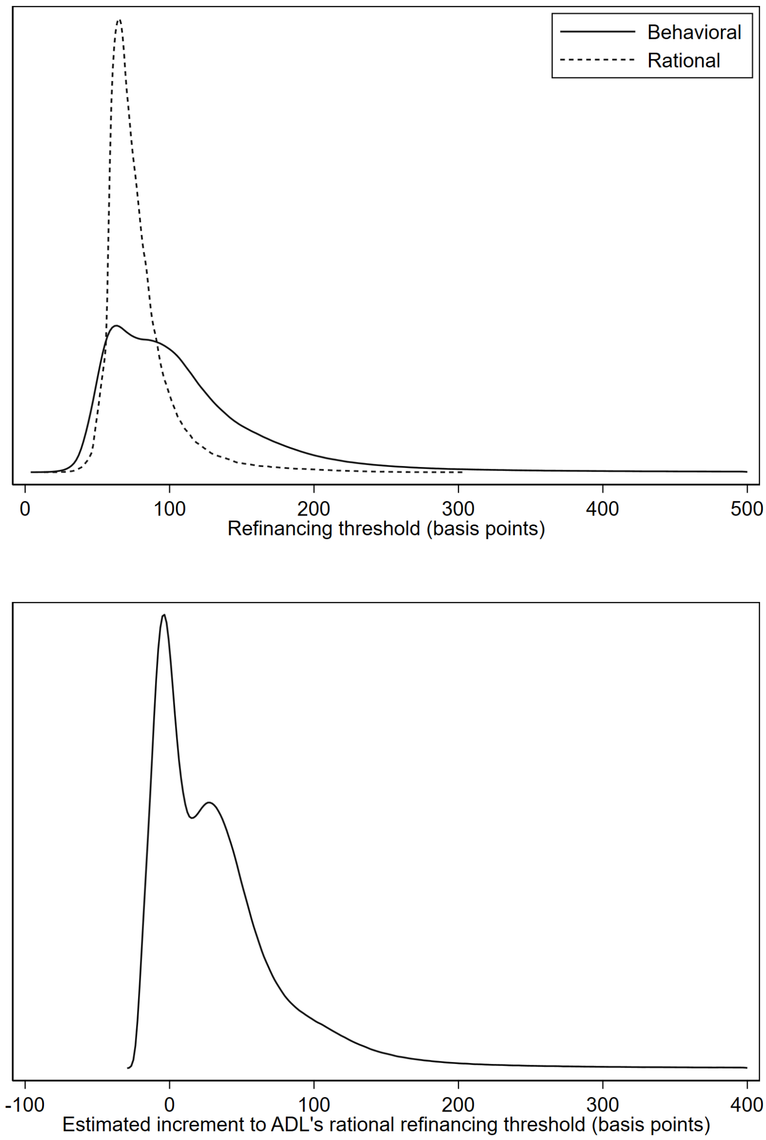


Figure 15: Behavioral refinancing threshold and ADL's rational counterpart—fixed exogenous mortgage termination rate. This figure compares the estimated optimal refinancing threshold given by the behavioral model with the optimal refinancing threshold given by the fully rational ADL model. The figure is based on the alternative estimates of the model from Table 7. The top plot shows the distribution of the estimated behavioral refinancing threshold (solid) and the distribution of the corresponding ADL refinancing threshold (short-dashed). The bottom plot shows the distribution of the difference between the behavioral refinancing threshold and the ADL refinancing threshold.

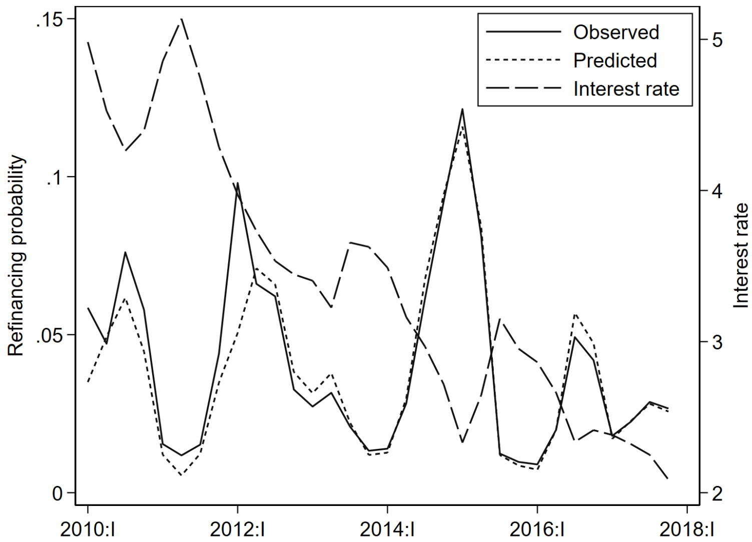


Figure 16: Observed and predicted refinancing probabilities—fixed exogenous mortgage termination rate. This figure illustrates the evolution of observed refinancing probabilities (solid), predicted refinancing probabilities by the behavioral refinancing model (short-dashed), and Danish mortgage interest rates (long-dashed) over the period from 2010 to 2017. The figure is based on the alternative estimates of the model from Table 7.

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