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State-aided Price Coordination in the Dutch Mortgage Market*

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Abstract

We show how price leadership bans, imposed as part of the European Commission's State aid control on all main mortgage providers except the largest bank, shifted the Dutch mortgage market from a competitive to a collusive price leadership equilibrium. In May 2009, mortgage rates in the Netherlands suddenly rose against the decreasing funding cost trend to almost a full percentage point above the Eurozone average. We derive equilibrium best-response functions, identify the price-leader, and estimate response adjustments in daily household mortgage rates between 2004 and 2012. Around the Spring of 2009, when the bans were collectively negotiated, we find structural decreases in the leader's cost pass-through, much closer following of its price, and strongly reduced transmissions of common cost changes into price-followers' mortgage rates. Indicative predicted overcharges are 125 basis points or 26%, on average.

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1 Introduction

In the Spring of 2009, interest rates on loans for home purchases in the Netherlands increased against a downward trend induced by the European Central Bank's (ECB) stepwise reductions of the policy rates, to become the highest in Europe by a margin. Figure 1 displays the average mortgage rate on different maturities in the Netherlands, neighboring countries, and the Eurozone average.[1] Whereas the Dutch rates used to be close to the average before the 2007-2009 financial crisis, from May 2009 they remain structurally above.

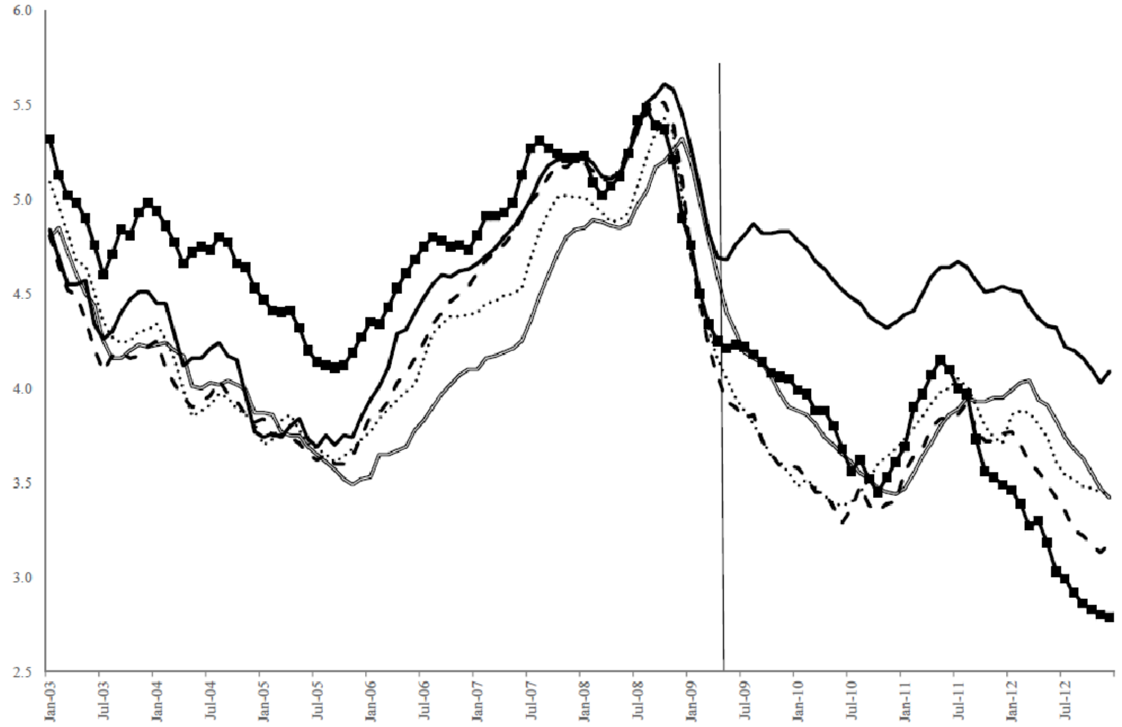

Figure 1: Average lending rate (in %) for house purchases in the Netherlands (solid line), the Euro area (long dash), Germany (blocked), France (open), and Belgium (dash).

Initially suspicious of collusion, the Netherlands Competition Authority (NMa) investigated in the Fall of 2010.[2] In May 2011, it reported no competition concerns

[1]Source: ECB Statistical Data Warehouse. Rates are in percentage, monthly, each maturity is weighted monthly by its share in total outstanding mortgages.

[2]NMa, *Quick Scan Hypotheekrente*, November 2010. The pilot study was a response to questions raised in Parliament in early September 2010.

on the basis of negative mean-variance tests.[3] The competition authority had been convinced that post-crisis Dutch mortgage rates could no longer be compared internationally, as abnormally high loan-to-value ratio's would have raised the costs of attracting mortgage funding even more for providers in the Netherlands. Margins over funding costs, defined in consultations with the banking sector, showed that against the falling base rates (Euribor and savings deposit rates), risk premiums (CDS and RMBS spreads) had increased. In addition, the banks faced higher regulatory cost, particularly for compliance with the Basel recapitalization rules. Combined, the NMa concluded that margins on mortgages had indeed been "historically high" for a period but had recently returned to "normal pre-crisis levels".[4]

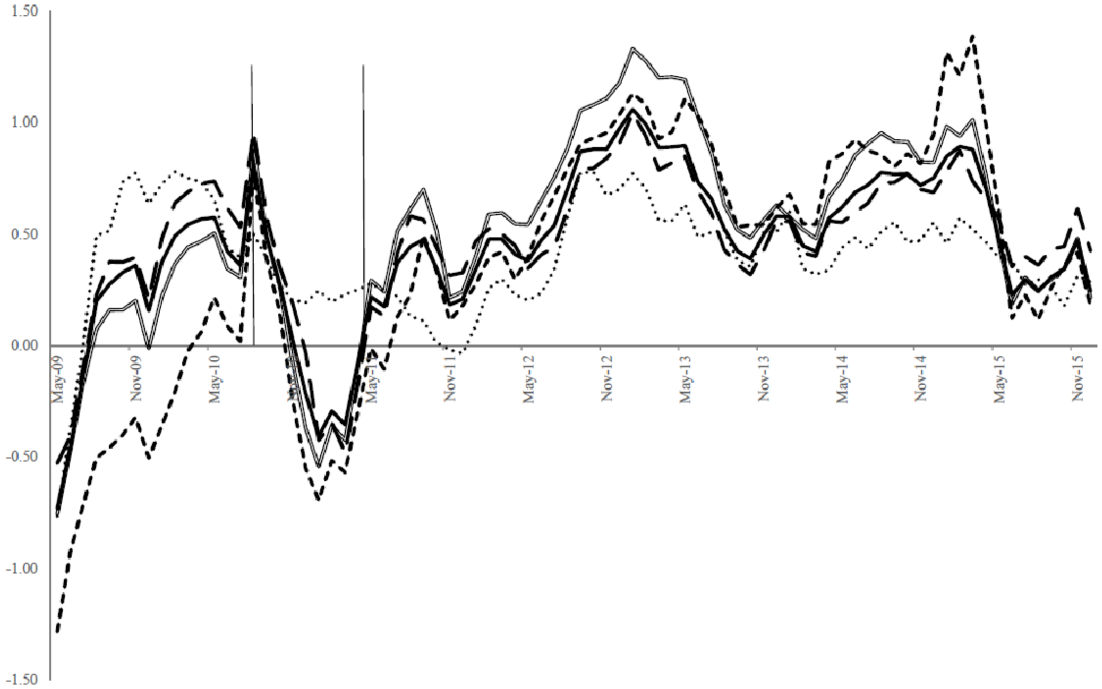

Figure 2: Extra margins on mortgage rates (percentage) since May 2009 by maturity: variable (dash), 1-5 years (long dash), 5-10 years (open), >10 years (medium dash), weighted average (solid).

However, directly after the publication of the NMa report, mortgage margins rose again to even higher levels. Figure 2 displays the margin by maturity since May 2009

[3] NMa, *Sectorstudie Hypotheekmarkt: Een Onderzoek naar de Concurrentieomstandigheden op de Nederlandse Hypotheekmarkt*, May 2011, hereafter NMa (2011).

[4] NMa (2011), page 3. It attributed the episode of high rates to the withdrawal of several small foreign challengers to their home markets in the crisis: the $C4$ and HHI had peaked in the first half of 2010—at 80 and 2000. See also Overvest and Tezel (2014), who handled the case.

in excess of the average margin before the crisis, according to the Dutch competition authority's margin calculation method.[5] The margin had returned to its pre-crisis average only for the exact duration of the competition authority's investigation. Neither increased funding costs, nor heightened market concentration alone, seem sufficient explanation for the structural markups.[6] Where mortgage rates had averaged roughly 4.5%, they rose to 4.75% after the height of the crisis in 2008, while at the same time marginal funding costs dropped by roughly 75 basis points. Why were mortgage rates suddenly about a hundred basis points high in the Low Countries?

In this paper we argue that price leadership bans, imposed by the European Commission as part of State aid remedies on all the main mortgage providers except price-leader Rabobank, shifted the Dutch mortgage credit market from a competitive to a collusive price leadership equilibrium. Price leadership bans are one of the Commission's behavioral tools for State aid control, which is an important part of European competition policy. The bans are intended to prevent an aid-recipient from misusing the government resources to compete predatorily on price. In this case, the pricing restrictions were pressed for in the Spring of 2009, and then acted as a coordination device. In a model based on Rotemberg and Saloner (1990) and Cooper (1997), that is calibrated to stylized statistics of the Dutch mortgage market at that time, we derive hypotheses on the effects of coordination by price leadership bans on the behavior of the price-leader, followers under a ban, and any remaining free fringe competitors.

The model predictions are tested on a large unique data set of daily rates on mortgages sold to households between 2004 and 2012 with fully insured default risk under the Netherlands' government mortgage guarantee program (NHG), which covers over 20% of the total outstanding mortgage debt. After identifying the price-leader, we estimate equilibrium best-response adjustments in cointegrating equations. Consistent with a shift from competitive to full coordination equilibrium, we find structural decreases in the leader's cost pass-through, a several times closer following of the leader's price, and a strong decrease of common cost pass-through into price-followers' mortgage rates. Structural breaks in competitive behavior are estimated in or around Spring 2009, when the price leadership bans were collectively negotiated with the Commission.

The paper is organized as follows. Section 2 provides more detail on the Dutch mortgage market situation and the policy intervention. Section 3 reviews related literature. Equilibrium best-responses of the leader and its followers in competition and collusion in a model of competitive barometric price leadership are characterized in Section 4. Section 5 provides descriptive statistics. In Section 6 the empirical strategy is set out. The main mortgage providers, in particular the price-leader Rabobank, are

[5] The pre-crisis average margin is taken between January 1, 2004, and August 31, 2008, just before the fall of the Lehman Brothers. The approach avoids the need to allocate fixed costs. See Dijkstra and Schinkel (2013).

[6] See Dijkstra *et al.* (2014) for a detailed discussion of the funding cost explanations.

identified in Section 7. In Section 8 the model is calibrated to formulate predictions characteristic of a competitive regime shift. Section 9 presents empirical findings. Section 10 sketches but-for mortgages rates, which may have been if the market had continued in competitive leadership. Section 11 concludes. Further details are given in an (online) appendix.

2 The Dutch Mortgage Market

The Dutch mortgage credit market has always been national and concentrated.[7] Houses are expensive and heavily mortgaged, commonly over five times the annual gross household income, in large part due to a generous fiscal stimulation of home-ownership.[8] As a result, demand is relatively stable, with an inelastic core, because mortgages are a mere necessity to (re)finance a Dutch home. In December 2009, the total outstanding mortgage debt in the Netherlands was €522 billion, or 84% of GDP, of which €53 billion were newly issued.[9] From the different maturity periods offered, most commonly sold were mortgages with a 10-year fixed interest rate.

Mortgage loans of the same maturity are close substitutes, as contract terms are largely the same between providers. Competition for new (re)financing is on price and hardly affects a provider's existing customer base with fixed interest period contracts, which typically include heavy prepayment penalty clauses. Default rates are low. Only when their mortgage term has ended, are borrowers free to switch providers. Banks and intermediaries worked on commission from the ultimate seller, so that customers had negligible search costs and paid no explicit fees for mortgage advice.[10]

Otherwise similar mortgage contracts are somewhat differentiated between providers, due to customer loyalty, borrower confidence, and local presence.[11] The market is concentrated. Three household name incumbents, Rabobank, ING, and ABN AMRO, each with their own nation-wide network of local branches, together provide 60 to 70% of all mortgages. Other providers had to rely on existing retail networks and committed less capacity. The smaller established providers SNS and AEGON served 5 to 10% each. Fringe entrants, such as DSB, Argenta or BNP Paribas, never had

[7] The European mortgage market is partitioned along Member State borders, due to varying and strict national regulations. There is little or no cross-border lending for house purchase. See the European Commission's long-running project *Mortgage Credit Directive 2014/17/EU*.

[8] Mortgage interest payments used to be tax deductible without limit, and full interest-only loans allowed—up to 50% in the case of NHG mortgages. Increasingly tighter restrictions were introduced in mortgage reforms implemented from January 2013.

[9] End of 2012, these totals were €538, 82% of GDP, and €55 billion. Source: De Nederlandsche Bank (DNB) Statistics.

[10] Commissions were prohibited in the 2013 mortgage reforms.

[11] Degryse and Ongena (2005) show that bank branch coverage affects competition and pricing. Van der Cruijsen and Diepstraten (2017) find a low switching propensity in retail banking, especially in Dutch mortgages.

more than a few to 5% market share each—20% together at most—despite lower rate offers.[12] Many of the foreign contestants withdrew from the Dutch market during the crisis and were long hesitant to (re)enter, due to high loan-to-value ratio's and regulatory uncertainty.[13]

Historically, Rabobank, with a steady 25% market share and being the largest provider, is the barometric price-leader in mortgages.[14] With its leading market research division, Rabobank is looked at for predicting housing market, macroeconomic, and interest rate developments ahead of the others.[15] In a weekly cycle, Rabobank sets its mortgage rates first, for the other providers to observe and determine their own offer rates. In competition, the threat of its followers undercutting disciplined the price-leader to price close to (its nearest rival's) funding costs.[16]

At the height of the financial crisis, in the autumn of 2008, with the exception of Rabobank, all the major Dutch banks needed government support to divert the threat of bankruptcy. State aid is strictly regulated under the European Treaty.[17] In this case, the European Commission only temporarily admitted the support as "emergency measures", but under requirements that were to be made precise later. These State aid conditions were negotiated at the beginning of 2009. The most prominent among them were restructuring and refinancing measures.

The price leadership ban commitments were intended to prevent an aided bank from undercutting competitors that had not needed aid. Rabobank had lobbied then European Commissioner for Competition, Neelie Kroes, for the bans.[18] In mortgage credit markets they forbade the recipient to offer lower rates than its rivals.

The first formal formulation of the bans is in the Commission's State aid decision for ING, of November 18, 2009, in which the Kingdom of the Netherlands commits that:

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[12] This market structure may have resulted from judo strategies, in which price-fighting entrants that commit to low capacity are accommodated by (a) stronger incumbent(s). See Gelman and Salop (1983).

[13] NMa (2011), pages 19-25 and KPMG Financial Services, *Barriers to Entry, Growth and Exit in the Retail Banking Market in the Netherlands*, 2014.

[14] Barometric price leadership was coined by Stigler (1947) as a form of competition in which one firm has taken on the role, for historical or institutional reasons, to pass information along to the rest of the industry. The leader is not dominant but "commands adherence of rivals to his price only because, and to the extent that, his price reflects market conditions with tolerable promptness." (*op.cit.*, page 446) Markham (1951) discusses price leadership informally as a collusive device, and Lanzilotti (1957) as competition.

[15] RaboResearch has over 140 analysts worldwide, around 40 based in its knowledge center in Utrecht, The Netherlands—including leading Dutch economists. One of its prime focusses is on the Dutch housing market, where Rabobank in 2009 had €201.3 billion in outstanding mortgage loans.

[16] De Haan and Sterken (2006; 2011) find competitive price leadership by the distinctly largest "bank A" in the pre-crises period October 1997 to July 2003.

[17] Treaty on the Functioning of the European Union (TFEU), Article 107.

[18] Testimony of Neelie Kroes in Kamerstukken II 2011/12, 31 980, nr. 62, *Reports of Public Hearings Parlementary Inquiry Financial System*, pages 1451-1452. See also Zembla, *Your Mortgage: a Cash Cow*, a documentary film that aired September 14, 2012.

> "Without prior authorization of the Commission, ING will not offer more favorable prices on standardized ING products [including retail mortgages] than its three best priced direct competitors with respect to EU-markets in which ING has a market share of more than 5%. (...) As soon as ING becomes aware of the fact that it [has become the price-leader on a retail mortgage market within the EU], ING will as soon as possible adjust, without any undue delay, its price level which is in accordance with this commitment."[19]

Similar pricing bans were imposed after on Fortis-ABN AMRO (February 2010), and AEGON (August 2010), and always expected for SNS REAAL.[20] The conditions were public and commonly understood to apply to any price divergence. Adherence was monitored by appointed trustees. The decision texts did not specify remedies, yet the bans were Member State commitments, so that an infringement would clearly have been consequential. The conditions applied (unrevised) for three years, or until the aid was paid back.

The imposition of the price bans was certain for the Dutch banks by the Spring of 2009. The aid-giving Member State formally proposes State aid measures, which the European Commission can then decide accept or not. In this case, the Netherlands Ministry of Finance and the Dutch Central Bank (DNB) collectively negotiated the conditions with the Commission for the Dutch banks. The Commission's first Communication in 2008, as well as its preliminary approvals of the emergency aid, mention the possibility of price restrictions being imposed. From the minutes of negotiation meetings with ING that became public, we know that at least for the first time on April 24, 2009 Kroes insisted the price bans be proposed.[21] Shortly after, a precedent was set when Commerzbank in Germany received one.[22]

In the super-concentrated Dutch market, the near market-wide price leadership bans seem to have become the nucleus around which market power crystallized. The European Commission had effectively graduated Rabobank to a must-follow price-leader, by no longer allowing the four biggest competitors of the bank to undercut its

[19] Commission decision 2010/608/EC of November 18, 2009 on State aid (ex N138/09) implemented by the Netherlands for ING's illiquid Assets Back-Up Facility and Restructuring Plan, recital 84. Excerpts in [...] are from related parts of the decision.

[20] On February 5, 2010, the Commission extended its conditional approvals of the State aid given to ABN AMRO and Fortis by decision 2010/C95/07 with additional measures that included a price leadership ban at recital 144. Commission decision 372/2009 of August 17, 2010 concerning AEGON, recital 116. SNS had received State aid in November 2008. While Commission decision 371/2009 of January 28, 2010 concerning SNS did not contain a price leadership ban, the final decision not to impose any was not made until end of 2013 (Kamerstuk 33 532, 2013).

[21] Judgment of the General Court of March 2, 2012 in Cases T-29/10 and T-33/10, *Kingdom of the Netherlands and ING, supported by De Nederlandsche Bank NV v European Commission*, recital 14.

[22] Commission decision C(2009) 3708 final: State aid N 244/2009, Commerzbank, Germany, of May 7, 2009, recital 71. The German mortgage market nevertheless remained competitive, as there were sufficiently many unconstrained suppliers.

rate.[23] With only a few small and much less efficient free fringe competitors left, it meant that if Rabobank raised its mortgage rates, the other main banks would have to follow, or risk being in violation of their State aid conditions.

3 Related Literature

This paper is the first to analyze effects of price leadership bans.[24] To that end, we extend the linear demand symmetric product differentiation duopoly model of barometric price leadership in Rotemberg and Saloner (1990) to n-firms with different marginal costs. The competitive equilibrium is based on Cooper (1997). Price leadership is sustained by asymmetric information on the differentiated demand with a stochastic intercept. The most efficient bank invests in obtaining market information and uses it to set its price first. The others infer from this signal what the leader knows and price follow. In competitive equilibrium, the leader is disciplined by its followers, but still benefits from leading if it is sufficiently more efficient and information costs are not too high.[25]

The fully collusive barometric price leadership equilibrium is characterized in Rotemberg and Saloner (1990) in an infinitely repeated setting for sufficiently high discount factors. A subgroup of the firms active in a market may be sustainable as a partial cartel that price leads a competitive fringe that benefits from the umbrella effect, as in d'Aspremont *et al.* (1983).[26] Harrington (2017) shows how coordination on collusive price leadership roles requires little communication.

The empirical literature on price leadership uses essentially two different methods of analysis: (variants of) price matching and Granger causality. When products are relatively homogeneous and prices are uniform across customers, price leadership may

[23] In a report to the European Commission, Beck *et al.* (2010), on page 56, warned: "Banks that are prevented from trying to be a market leader just become passive followers exerting no real competitive discipline on their rivals, as though in some publicly-sponsored cartel."

[24] On the legal literature on State aid to banks, including also descriptions of price leadership bans, see Laprévote *et al.* (2017).

[25] Alternative explanations offered in the literature for why a firm would take on the price leadership role in competition are consistent with the largest and most efficient firm leading. Deneckere and Kovenock (1992) show for a duopoly of firms that differ in capacity, the larger firm would be willing to lead in competitive equilibrium. In Deneckere *et al.* (1992), firms differ in customer loyalty and the one with the larger loyal segment emerges as the competitive price-leader. In Van Damme and Hurkens (2004) the benefit of leading is to avoid risks that come with waiting, which is largest for the low-cost firm. In Pastine and Pastine (2004) there are costs of delay and the firm with the shorter reaction time or the lowest cost of delay emerges as the leader. Amir and Stepanova (2006) demonstrate in a Bertrand duopoly with asymmetric costs that the low-cost firm has an advantage in leading.

[26] Collusive price leadership may also facilitate monitoring. In Ishibashi (2008) the firm with the largest capacity, and thus the potential to serve the entire market, leads to commit not to deviate. In Mouraviev and Rey (2011) instead the least efficient firm, which has the strongest incentive to undercut the cartel, prices first, making it easier to punish it for deviations.

be inferred from price movement matching. Cao *et al.* (2000) establish price leading by better informed full-service brokers during the Nasdaq preopening, analyzing ratios of sequential nonbinding quotes. Seaton and Waterson (2013) offer as a falsifiable definition of price leadership that within a predetermined short period a price change is exactly matched on the same products more often than by chance. They find many instances in the British supermarket duopoly, both upward, mostly by the larger firm, and downward, mostly by the smaller. Even though the price increases are bigger, raising the price level over time, they conclude that the price leadership is competitive because price decreases are more quickly matched. With some more flexibility in the price matching Alé Chilet (2018) finds collusive price leadership in Chilean retail pharmacies, where upward movements are matched within a couple of days.

Price leadership in Edgeworth cycles has been studied extensively by direct price comparisons in gasoline markets. Eckert (2003) finds them in Canadian cities where there are also small gas stations present. Wang (2009) studies the timing of periodical pricing above competitive level. Using detailed analysis of the timing of price changes by gasoline stations in the Midwestern US, Lewis (2012) attributes the price restorations to a particular retail chain in each city. Collusive price-leaders are identified by many other stations matching their price increases within hours. Clark and Houde (2013) find delays in price following in a documented cartel case in gasoline in Canada, which they interpret as a transfer mechanism to sustain collusion amongst heterogeneous firms. Byrne and De Roos (2019) in Australian gasoline show that price leadership signals focal points that coordinate market prices.

In markets in which products and prices are somewhat differentiated, Granger-causality from one player's prices to another's is inferred using vector-autoregressive and error correction models. In Canadian newsprint, a market known to be characterized by barometric leadership over a large number of producers, Booth *et al.* (1991) find only moderate markups estimating the leader's response to cost changes. Based on Granger causality, Peiers (1997) identifies Deutsche Bank as the asymmetrically informed price-leader in foreign exchange markets and Berck *et al.* (2008) sales promotion leadership in orange juice in U.S. groceries. In Italy, Andreoli-Versbach and Franck (2015) establish endogenous price leadership in petrol and Bergantino *et al.* (2018) in domestic travel by air and rail.

In mortgage markets, where interest rates and cost factors are commonly found to cointegrate, error-correction models are used to assess rate responses to (mostly a single) cost proxy, including in Valadkhani (2013) for Australia, Allen and McVanel (2009) for Canada, Cecchin (2011) for Switzerland, and Francke *et al.* (2014) for the Netherlands. De Haan and Sterken (2006, 2011) conclude competitive barometric price leadership in the pre-crisis Dutch mortgage market from close following in daily mortgage rates of the interest rate on 10-year government bonds. Toolsema and Jacobs (2007) find in an earlier sample that rate increases are followed somewhat more closely than decreases.

4 Price Leadership in Mortgage Banking

We set up a stylized model of barometric price leadership that is fitting to the mode of competition in Dutch mortgages in Section 4.1. Sections 4.2 and 4.3 characterize the competitive and coordinated price leadership equilibria, respectively.

4.1 A Model of Barometric Leadership

Let n providers $i = l, 2, ..., n$ compete for the (re)financing of a given mortgage type, that is somewhat differentiated between them, reflecting differences in the contract terms, long-term relationships in other banking products, and brand image. All banks attract funding at constant marginal costs, which may be constituted by various sources and include credit default risk and regulation. The first bank l operates at the lowest marginal funding cost c_l. Without loss of generality, we rank the other $(n-1)$ banks $i \neq l$ in order of their somewhat higher marginal costs $c_{i \neq l}$ non-decreasing.

If bank l acts as the price-leader, it sets its mortgage rate r_l first. The other banks observe r_l and simultaneously set their rates $r_{i \neq l}$ optimally in response shortly after. Demand for the mortgage offered by bank i in role $t = \{l, f\}$ depends on mortgage rate differences

$$Q_i = a_t - br_i + d \left(\frac{1}{n} \sum_{j=1}^{n} r_j - r_i \right), \tag{1}$$

in which a_t is a stochastic intercept that differs between the leader and the followers, b a common slope and d a product differentiation parameter—the larger d, the more homogeneous mortgages are. While product differentiation is symmetric, funding cost differences between the providers generate equilibrium price dispersion. Heterogeneity across providers also reflects that rate offers would in part be predicated on a provider's portfolio constitution and regulatory requirements.

All banks have full information about the structure and parameters of the model, except for the intercepts a_t. A common intercept shock a affects all firms in the same way, while an idiosyncratic shock e affects the leader differently from the followers. Let

$$a = \frac{a_l + a_f}{2} \text{ and } e = \frac{a_l - a_f}{2},$$

so that $a_l = a + e$ and $a_f = a - e$. We assume that a and e are independently distributed over time: a with mean $\overline{a} > 0$ and variance σ_a^2, e with mean 0 and variance $\sigma_e^2 \leq \sigma_a^2$. Their distributions are common knowledge. Hence, in expectation, the leader and its followers have the same demand intercept, their histories are not informative and $a > e$ most of the time—or the followers do not participate.

The values of a and e drawn for the period can be known as a lump sum information cost I. In barometric price leadership equilibrium, bank l makes this investment, which is observable, and uses it to set its rate first. The other bank(s) follow and deduce information on the values of a and e from the leader's price. The information extracted from the leader's price signal is not perfect, however, since the followers will only be able to distill information about a_l, whereas ideally they would want to know a_f. The leader knows that its price conveys information to the followers, but is not fully informative.

Note that if $\sigma_e^2 = 0$, the followers receive a perfect signal. Equilibrium values will depend on the combination of variances

$$s = \frac{\sigma_a^2 - \sigma_e^2}{\sigma_a^2 + \sigma_e^2},$$

which is between 0 and certainty equivalence value 1. Since common demand shocks must be larger than idiosyncratic shocks, $s > 0$.

4.2 Competitive Price Leadership

In the competitive price leadership equilibrium, bank l is disciplined not to markup too high. The leader determines its strategy by first considering the subgame perfect equilibrium under imperfect information between the followers for any optimal value of r_l, and subsequently maximizing its own profits, taking the followers' optimal responses into account. The leader sets r_l^*, to which the followers respond simultaneously with $\mathbf{r}_{i \neq l}^*$. If all banks had the same marginal funding costs, followers obtained a higher profit than the leader, even if information was free. However, if the leader has sufficiently lower cost than the followers, it can recoup its investment $I > 0$ and still make a higher profit than the followers.

Let $\Delta c = c_2 - c_l > 0$ and $\left(r_l^*, \mathbf{r}_{i \neq l}^*\right)$ the unique rates that solve the barometric price leadership model.[27] For a high enough $\Delta c > 0$ and a low enough $I > 0$, the leader earns a higher profit than any follower, that is, $\pi_l^* > \pi_{i \neq l}^*$ for all $i = 2, ..., n$. The rates constitute a competitive equilibrium if the leader has no incentive not to invest in information and/or not to lead, and no follower is better off also investing in I and/or also leading. This is the case for intermediate values of I, and s not too high. If I is too high, the price-leader no longer invests in information yet price leads. If I is too low and s too high, (the most efficient) follower(s) want(s) to become fully informed by also investing in market information.[28]

We thus obtain that the barometric price leadership of the more efficient and informed bank is an equilibrium for reasonable uncertainty, funding cost differences, and information costs.

[27] The equilibrium is fully characterized in Appendix A, equations (28) and (29).

[28] Unilateral deviation by a bank from its role as leader or follower implies different games. If the leader refused to lead, a simultaneous move price game between all the banks would result. Unilateral deviation by a follower to also lead creates a duopoly simultaneous move price-setting game by the two different 'leaders', taking into account the remaining $n-2$ followers' best-responses, with information extraction depending on which bank(s) invest I. In general, competition is more intense, resulting in lower profits.

Proposition 1 *For bounded positive values of s , I and Δc, $\left(r_l^*, \mathbf{r}_{i\neq l}^*\right)$ is a competitive equilibrium in which the most efficient bank l acts as barometric price-leader.*

Note that followers with a small enough difference in marginal funding costs to the leader undercut the leader's rate in equilibrium. All sufficiently less efficient followers price above the leader in equilibrium.

The competitive price leadership equilibrium response of follower i's mortgage rate $r_{i\neq l}^*$ to the leader's equilibrium rate r_l^* is a linear function with fixed parameters in r_l, c_l (as the followers learn from r_l), and the individual costs of $c_{i\neq l}$ and all other followers

$$r_{i\neq l}^* = B_{i\neq l,0} + B_{i\neq l,1} r_l^* + B_{i\neq l,21} c_{i\neq l} + B_{i\neq l,22} c_l + B_{i\neq l,23} \sum_{k\neq i\neq l}^{n-2} c_k, \tag{2}$$

in which the constituted B-parameters are all functions of n, b, d, σ_a^2 and σ_e^2.

To changes in the leader's rate, r_l^*, each follower's response is the same, despite possible costs differences

$$\frac{dr_{i\neq l}^*}{dr_l^*} = B_{i\neq l,1} = \frac{d + (2bn + 2d(n-1))\, s}{(2b+d)\, n + 2d(n-1)\, s}, \tag{3}$$

which decreases in n and increases in s and d between 0 (for $d \to 0$, $s = 0$) and 1 ($n = 1$). Furthermore, $B_{i\neq l,21} \gg (B_{i\neq l,22}, B_{i\neq l,23})$.

Knowing its followers' equilibrium responses, the price-leader sets its rate based on costs first. In competitive equilibrium, it is

$$r_l^* = B_{l,0} + B_{l,21} c_l + B_{l,22} \sum_{i\neq l}^{n-1} c_i, \tag{4}$$

with $B_{l,21} \gg B_{l,22}$.

4.3 Coordinated Price Leadership

The imposition of price leadership bans softens competition by reducing the number of followers that remain free to undercut the leader and/or each other. The precise impact of the bans on competition depends on the total number of competitors, their marginal cost differences, and how many and which of the banks are banned. In the Dutch case, the four largest and most efficient competitors of Rabobank received a ban specifying that they could not offer a mortgage rate lower than the three cheapest rates in the market. It left only a few small and less efficient fringe competitors free to undercut. Depending on their number, the bans could have fully eliminated the competition.

To see this, let $n_B \geq 0$ be the number of banks under a price leadership ban, so that only $n - n_B - 1$ followers remain unconstrained in their pricing. Suppose that the assumption that marginal funding costs only somewhat differ between the banks imply that all follower-banks would want to undercut bank l's higher monopoly price $r_l^{PLB} = \frac{a+e}{2b} + \frac{1}{2}c_l$—where the superscript PLB refers to pricing in the regime with the price leadership bans. First suppose that the n_B banks that are restricted by a ban are the most efficient banks, after bank l, which all have low enough marginal costs to undercut the price-leader in competitive equilibrium. These followers' best responses to any rate set by bank l that is higher than the competitive level is also to price below, so that not allowed to undercut, they set $r_{i \neq l}^{PLB} = r_l^{PLB}$ to any rate r_l^{PLB}.

Next, consider a ban on one or more of the less efficient followers that would have priced above bank l in competitive equilibrium, and possibly some price range above the leader's rate in competition. Since by construction of the marginal cost differences, even the least efficient follower-bank would want to undercut bank l's monopoly rate, at some price level r_l^{PLB} high enough the constraint $r_{i \neq l}^{PLB} \geq r_l^{PLB}$ becomes binding for all followers under a ban.

Finally, note that in case three or more free fringe competitors remain, the banks under a ban are not restricted by the higher rate r_l^{PLB}, but also satisfy the ban by not pricing lower than the level of the third least efficient of the ban-free banks, if these are lower than r_l^{PLB}. The price-leader aware of this will raise its rate, but not by as much as when the following banks under a ban cannot price below the leader's rate at all. However, since $n - n_B \leq 3$, there are at most two followers free to price low, so that it is not possible for a bank under a ban to price below bank l while still pricing above at least three "nearest" competitors. Hence, it must be that $r_{i \neq l}^{PLB} = r_l^{PLB}$ for all banks $i \neq l$ under a price leadership ban.

We arrive at the following result.

Proposition 2 *For $n - n_B \leq 3$, for r_l^{PLB} high enough, $r_{i \neq l}^{PLB} = r_l^{PLB}$ for all banks $i \neq l$ under a price leadership ban.*

The bans thus peg the mortgage rates of the banks under a ban, either to the leader's rate or to that of the third most efficient free follower-bank, if there are so many. Competition is most restricted, therefore, if the more efficient banks are placed under a price leadership ban, so that the less efficient banks restrict the prices of the banks under a ban at a high level from below. If all but two competitors receive a price leadership ban, the price-leader knows that when it raises its price enough, from a level below bank l's monopoly rate, all followers under a ban are bound to set the same price as the leader.

The increased rate level at which the price-leader optimally profits from this situation depends on which of the follower-banks are eliminated as competitors by a ban, and the strength of the remaining free fringe competition. If no significant fringe remains, $n_B \geq n - 3$ bans give the price-leader a *de facto* monopoly, so that the fully coordinated equilibrium is reached: the followers copy the price that the leader sets by maximizing its own profits without constraint.[29]

As long as the free fringe constitutes a competitive threat, the effects of the price bans may be analyzed as an asymmetric competitive barometric price leadership with $n - n_B$ players. Bank l sets its rate first, to which it knows the rates of n_B of its followers are ban-pegged—provided the price rise is sufficient for the followers to want to undercut, given their relative efficiencies. The fringe followers price simultaneous next, benefitting from an umbrella effect caused by the ban's partial coordination, but still somewhat discipline the price peloton.[30]

Under the conditions of Proposition 2 and a sufficiently high rate increase, the response of the followers under a price leadership ban to changes in the leader's rate will no longer be according to (3), but instantaneous and complete. That is,

$$\frac{dr_{i\neq l}^{PLB}}{dr_l^{PLB}} = 1, \tag{5}$$

for all banks under a ban, irrespective of any remaining fringe competition. Any follower bank(s) that are not under a price ban respond by (3) for $n - n_B$ players, which is bounded away from 1.

5 Data and Descriptive Statistics

Our data set contains all new and renewed (partly) amortized mortgage contracts of various maturities, signed daily on workdays between January 1, 2004 and December 12, 2012, just before the mortgage reforms, under a Netherlands government mortgage guarantee program (Nationale Hypotheek Garantie, NHG), which insures commercial mortgage providers against residual mortgage debt in case of foreclosure.[31] In 2009, the total outstanding NHG guaranteed mortgage debt was €109 billion, of which €17 billion was newly issued. In 2012, these numbers had risen to €154 and €19 billion.[32] NHG-backed mortgages present a low credit risk to the mortgage provider, which allows them to offer lower interest rates. The sample of NHG-backed mortgages is relatively homogeneous in terms of both risk profile and house size, because the loan provider is insured against default and limits are imposed on the size of the mortgage.[33]

[29] This is the collusive equilibrium for high enough discount factors in the infinitely repeated barometric price leader stage game in Rotemberg and Saloner (1990).

[30] See D'Aspremont *et al.* (1983).

[31] The data sources are detailed in Appendix *B*.

[32] Source: WEW Annual Report 2009; WEW Annual Report 2012.

[33] The NHG is administered by the WEW, a fund that is financed through nominal entrance fees paid by qualifying mortgage takers. Strict upperbounds apply to income and only houses up to a set price ceiling are eligible for an NHG. This ceiling was €265k for most of our sample period, with an exception for the period 2009-2011 when it was raised to €350k to stimulate housing demand in the wake of the financial crisis. This limits the sample to mortgages on houses with a below average price on the Dutch market, which are typically fully mortgage financed.

The data set includes observations on 974,864 closed mortgage contracts. Each observation contains information on the contract date, the (anonymized) mortgage provider, the loan duration, the loan amount, loan type (duration of the fixed interest rate), and the effective interest rate.[34] The shares of mortgages by maturity are: variable .5%, 1-9 years 18.4%, 10 years 55.5%, 11-19 years 10.1%, 20 years 10.1% and over 20 years 5.3%. The average mortgage was for €170,548.

The mortgage provider of each contract is unknown. We have labeled them A to H by share of total mortgages sold. Of the total number of mortgage contracts, bank A sold (in thousands) 178 (18%), bank B 109 (11%), followed by four providers with between 60 and 70 (6 to 7%) closed mortgage contracts each. Banks G and H each closed around 50 (5%) mortgages. The other providers were considerably smaller, with the next largest provider supplying 35 (3.5%).

Table 5.1: Sample statistics

		before		after		full sample				
maturity	N	mean	std dev	mean	std dev	mean	std dev	median	min	max
var	100558	4.39	1.15	4.68	.62	4.63	.76	4.80	1.00	6.78
1-5	33127	3.94	1.28	4.62	.81	4.20	1.17	4.30	1.00	7.80
5	61240	4.45	.93	4.10	.53	4.25	.75	4.05	1.00	8.14
5-10	100367	3.99	.54	4.54	.55	4.02	.55	4.00	.88	8.98
10	420242	4.53	.60	4.74	.40	4.65	.51	4.70	.50	10.38
>10	259330	4.68	.55	5.17	.54	4.84	.60	4.80	.70	13.50
all	974864	4.45	.71	4.76	.40	4.65	.51	4.70	.50	13.50
r_{base}		3.98	.70	2.44	1.11	3.27	3.52	1.20	.07	5.36
r_{Eonia}		2.78	.89	.52	.31	1.73	2.02	1.32	.07	4.60
$r_{deposit}$		2.62	.35	2.18	.22	2.42	2.40	.30	1.96	3.19
CDS_{Rabo}		.28	.39	.93	.40	.58	.43	.51	.00	2.13
CDS_{ING}		.33	.40	1.37	.69	.81	.64	.75	.01	2.92
CDS_{ABN}		.32	.36	1.17	.26	.72	.77	.53	.01	2.13
CDS_{AEGON}		.73	1.05	2.00	.72	1.32	1.14	1.11	.02	6.74
CDS_{SNS}		.68	1.27	2.83	1.02	1.67	1.43	1.58	.02	8.25
$RMBS$		1.39	2.02	2.00	1.19	1.81	1.52	1.39	.08	8.44
$Tier1$		9.71	.41	11.85	.35	10.70	9.47	1.14	9.00	12.40
HHI		.079	.012	.110	.014	.093	.095	.020	.057	.279

Notes: maturity in years; rates in %; break at May 1, 2009.

Data on the costs of obtaining funding for mortgages in the deposit, money, and capital markets include various interest and swap rates. Obtained from the Dutch Central Bank (DNB) are data on interest rates on deposits (monthly), the interbank swap rate as a base rate (daily, differentiated by maturity), the overnight Eonia

[34] Mortgage rates were registered on contract dates, whereas typically some time passes between quotation and contract signing—with limited space for price negotiations. The period that a rate offer remains valid differs per provider, between two to seven months. Using the contract date may therefore not fully capture the exact timing of the interest rate responses. The WEW supplied us with additional information on offer dates, which we were able to connect to the contract dates. The contract rates correlate highly with the window rates. Findings using the offer dates are less pronounced, in part reflecting matching issues.

rate (daily) and the quarterly ratio of Tier1-capital to risk-weighted assets as an average for all Dutch banks. Credit Default Swaps (CDS, daily, differentiated by maturity) were obtained for the five largest Dutch mortgage providers from Thomson Datastream, and Residential Mortgage-Backed Securities (RMBS, daily, differentiated by maturity) from Markit, which is available from 2006 only. The monthly Herfindahl-Hirschman-index (HHI) was calculated from the NHG mortgages data set on a monthly basis over all maturities.

Table 5.1 summarizes the information in the data set over the entire period, as well as before and after May 1, 2009 as the approximate date at which the price leadership bans may have taken effect. Average rates for almost all maturities are structurally higher in the after-period, while their standard deviations decreased. The mean-to-variance ratio for all maturities increased, close to doubling for most, which is consistent with coordination. The base rate, Eonia, and deposit rates fell steeply after May 1, 2009, due to monetary policy interventions. At the same time, CDS spreads increased as a combined result of increased risk, enhanced risk-pricing, and a higher risk aversion of investors in the wake of the financial crisis—in part regulation-induced.

The risk premiums of AEGON and SNS are higher and display a higher increase than Rabobank, ING, and ABN AMRO. This may reflect implicit State aid guarantees that the latter enjoyed because of their status as systemic banks. CDS_{Rabo} is the lowest by a margin also amongst the latter three banks. Rabobank had better access to securitization, and front-loaded its long-term capital mortgage funding, amongst other things by regularly issuing (covered) bonds.[35] These cost differences are consistent with the conditions in Proposition 1 for equilibrium price leadership by Rabobank.

Table 5.2: Mortgages sold per week

bank	before	after (all)	after (< 265k)
A	321	459	271
B	170	317	186
C	100	219	130
D	96	214	125
E	111	168	102
F	135	131	81
G	102	118	73
H	114	91	58
total (excl. fringe)	1149	1718	1028
total (incl. fringe)	1854	2356	1423

Notes: break at May 1, 2009.

Table 5.2 gives the number of mortgages closed per week before and after May 1, 2009. In the last column, mortgages over €265k are excluded, as in July the NHG

[35] See Treur and Boonstra (2014).

upper-bound was extended to €350k in an attempt to stimulate demand. Corrected for the new category of higher end mortgages, sales are relatively stable. In combination with the slight increase in mortgage rates, this suggests relatively stable market demand—including price-inelastic refinanced mortgages of which the fixed interest rate period had expired. Demand did shift somewhat from the smaller to the larger providers.

6 Empirical Strategy

We analyze whether there is evidence of a shift from a competitive to a collusive price leadership equilibrium in the Dutch mortgage credit market around the time the European Commission imposed price leadership bans in four steps. First we conjecture the identities of the main banks. In particular, we determine the price-leader by estimating which bank is most likely to Granger-cause the interest rate of the other banks. Note it is not necessary for the main analysis to know the identity of individual follower-banks as well, since we expect them to behave similarly once they are under a price leadership ban. Yet we are reasonably certain of most of the main followers' names as well.

Second, we roughly calibrate the model developed in Section 4 to stylized facts of the Dutch market for NHG mortgages at that time. This allows us to derive predictions to test about pronounced differences between competitive and coordinated price leadership in responses to changes in funding costs and the leader's rate.

Third, the price-leader's rate is regressed according to its equilibrium pricing rule, with a dummy after the estimated break date. We determine whether and when the responsiveness of price-leader to cost changes breaks structurally over time over all maturities, using a Quandt-Andrews test for all days between January 1, 2008 to December 31, 2010 as potential candidate single break dates. In addition, the monthly HHI is included to control for market concentration.

Fourth, we regress the rates of each of the main followers with the largest market shares pairwise on the rate of bank A plus cost factors, according to the structure of a follower's equilibrium best-response function.[36] The break date is determined for each follower separately using the Quandt-Andrews test.

The best-response approach to identifying regime shifts is appropriate, despite the mortgage rate time-series in our sample displaying unit roots in levels, which is typical in daily interest rate data.[37] Nominal mortgage rate values are generally tightly bound between zero and an upper bound that derives from credit constraints.[38] In our sample, the range is .5 to 13.5%. Moreover, there are no unit roots in first

[36] Appendix C shows how the followers' rate responses are likely to be overestimated if cost changes are not controlled for.

[37] Appendix D gives non-stationarity test results on the daily 10-year maturity average mortgage rate series, which is the most sold type of NHG-backed mortgage.

[38] See Holmstrom and Tirole (1997).

differences, and the time-series display pairwise cointegration between the rates of the leader and the followers. This implies that estimations of the first differences in a maturity type can be interpreted as short-run deviations from the long-run equilibrium best-response functions. A fast return to equilibrium supports the results in levels.

It is not possible to distinguish empirically between the costs of the leader and the follower-banks. The banks' costs for getting the funds to supply the mortgages consist of various components that enter into a complex and unknown cost function. They are a mix of base and deposit rates, premiums and regulatory costs, none of which are necessarily matched with maturities. In addition, most cost factors on which data is available are common to all banks, such as the policy rate, or averaged over all banks, such as deposit rates. The exception is information on CDS spreads for the large Dutch banks Rabobank, ING, ABN AMRO, AEGON, and SNS, which we are, however, not able to identify with certainty.

For this reason, we include the same nine relevant cost factors as inputs for all the regressions simultaneously. This gives the model the most freedom of estimation and is in line with the theory that all costs in principle (indirectly) matter for all equilibrium rates. However, since the cost factors in our data set are all affected similarly and simultaneously by underlying fundamentals in financial markets, they are highly collinear, so that the cost coefficients cannot be interpreted individually.[39] Therefore some of the model predictions, for example switches in the roles of $c_{i \neq l}$ and c_l in explaining $r_{i \neq l}$, are not independently testable. For the prime analysis of the interest rate of the price-leader on the interest rates of the other mortgage providers, only multicollinearity with the leader's rate would be a concern. However, none of the cost factors is highly correlated with r_A, except the RMBS spread, which we therefore excluded.[40] This is the reason also for not including other candidate controls, such as rates on government bonds.

Instead, we analyze common cost changes. The extent of pass-through of changes in the leader's funding costs into its competitive equilibrium mortgage rate can be analyzed by the unweighted sum of cost coefficients

$$S_l = B_{l,21} + (n-1)\, B_{l,22}, \tag{6}$$

which increases in n and d between $\frac{1}{2}$ (for $d \to 0$) and 1 (for $d \to \infty$).

A related measure is the cost pass-through elasticity, which for the leader is defined as

$$T_l = \left(\frac{dr_l^*}{dc_l} c_l + \sum_{i \neq l}^{n-1} \frac{dr_l^*}{dc_i} c_i \right) \frac{1}{r_l^*}. \tag{7}$$

[39] The correlation table is given in Appendix E.

[40] Since NHG mortgages are fully secured, the risk premium is less relevant, and excluding the RMBS spread leaves a longer sample period, because it is not available before 2006. Including RMBS in the (shorter) estimations does not qualitatively change the results.

In the model, $T_l > 0$ for $d = 0$ and increases in more competitive oligopoly (n, d) to 1 ($d \to \infty$).[41] The two pass-through measures are highly correlated for small changes in (costs and therefore) equilibrium rates.

A follower's total unweighted common cost shock response consists of two parts:

$$S_{i \neq l} = B_{i \neq l,21} + B_{i \neq l,22} + (n-2)\, B_{i \neq l,23} + B_{i \neq l,1} S_l. \tag{8}$$

The first part is the direct cost pass-through, $S^d_{i \neq l} = B_{i \neq l,21} + B_{i \neq l,22} + (n-2)\, B_{i \neq l,23}$, which increases in competition (n and d), between $\frac{1}{2}(1-s)$ and $\frac{n-1}{n+2s(n-1)}$. The last component of (8) is an equilibrium effect through the price leader's rate. Combined, $S_{i \neq l}$ is between $\frac{1}{2}$ ($d \to 0$) and 1 ($d \to \infty$).

Follower i's cost pass-through elasticity is

$$T_{i \neq l} = \left(\frac{dr^*_{i \neq l}}{dc_{i \neq l}} c_{i \neq l} + \frac{dr^*_{i \neq l}}{dc_l} c_l + \sum_{k \neq i \neq l}^{n-2} \frac{dr^*_{i \neq l}}{dc_k} c_k \right) \frac{1}{r^*_{i \neq l}} + \frac{dr^*_{i \neq l}}{dr^*_l} T_l, \tag{9}$$

which also has a direct own-cost effect, and an equilibrium effect through the price leader's rate. In unconstrained pricing, both parts are strictly positive in monopoly and increasing in competition to 1 ($d \to \infty$). $S_{i \neq l}$ and $T_{i \neq l}$ are perfectly correlated for infinitesimal cost changes for each $i \neq l$.

After imposition of the price leadership bans, those followers under a ban will no longer respond to changes in their own costs, but much stronger to variations in the leader's cost, through the latter's rate changes. The price-leader's rate response to common cost changes will also be markedly different after the bans, in particular in the full coordination scenario, in which none of the followers' costs matter anymore to the monopoly leader. That is, $S_{i \neq l} = S_l = \frac{1}{2}$ and $T_{i \neq l} = T_l = \frac{c_l}{2r^*_l}$. With remaining fringe competition, both measures decrease much less, since the leader remains responsive to the fringe followers' costs, so that strong decreases are indicative of a weak competitive fringe.

The sums of the cost parameters, estimated in the third and fourth step for the leader and the followers respectively, are the exact measures S_l and $S_{i \neq l}$, since the individual cost coefficients implicitly estimate the weights of the cost component in the cost functions of all individual banks.[42] Also, any shifts in the funding composition over time would level out. Nevertheless, we note that the summation of a larger number of coefficients can accumulate beyond its theoretical upper-bound of unity, as the cost coefficients will pick up the effect of a cost function that is more complex than our linear specification.

The monotonic behavior of the cost pass-through elasticities T_l and $T_{i \neq l}$ in the level of competition allows for an addition competitive regime change test. We regress for

[41] On the pass-through elasticity in the price version of the Panzar-Rosse test, see Bikker *et al.* (2012). Weyl and Fabinger (2013) analyze the pass-through rate.

[42] The identity is established in Appendix *F*.

each mortgage provider the log of its rate on the log of all cost factors, using $\ln HHI$ as a control. The sum of estimated cost parameters is its elasticity. Applied to the price-followers, however, a standard estimation of T_f has a misspecification bias since it does not take into account the follower's equilibrium response to the leader's rate change in reaction to the common cost change. For this reason, we also estimate a log-specification of the price-followers equilibrium best-response that includes the leader's rate as a control variable.

7 Bank Identification

The identities of the eight mortgage providers that are largest in terms of the total number of mortgages sold over the entire sample period, banks A to H, can be conjectured with reasonable certainty. A first source of identification is the annual report that the WEW publishes. From 2006 onwards, for each year it provides the names of the biggest (5 in 2006-2010 and 10 in 2011-2012) suppliers of NHG-backed mortgages and the number of NHG mortgages that each sold. These identified market shares are nearly identical to those obtained from our sample: bank A correlates (ρ) closely with Rabobank (.97), bank B with ING (.95), bank C with AEGON (.94), and bank D with ABN AMRO (.97).

Two pronounced patterns in the sales of NHG-backed mortgages further help identification. First, bank A supplied almost no variable rate contracts in any year: between 5-18 each year out of approximately twenty thousand mortgages sold, or less than .1%. This is consistent with Rabobank's policy not to be active in this market segment. Second, from 2008/2009 onwards, bank B's sales of variable mortgages soared, at the expense of the longer maturities.[43] This pattern was noted in ING policy documents, and attributed to ING being the only major bank that continued to base its variables rates on the (low) Euribor. The substitution also reduced the bank's exposure to interest rate risk as a crisis response.

The remaining banks cannot be unambiguously distinguished in this manner. Bank H had a significant market share in the periods 2006-2007 and 2011-2012, but sold almost no mortgages in the Netherlands during the years 2008 and 2009. It is likely to be Argenta, a Belgian insurer that was active in the Dutch market before and after the financial crisis, but withdrew to its home market in the period 2008-2009. Bank G may be Obvion, a subsidiary of Rabobank. Banks E and F could either be SNS or Fortis—although one of them may also be a subsidiary of ABN AMRO.

Consistent with the theory of the price-leader with a funding cost advantage, Rabobank's CDS spread is lowest throughout—see Table 5.1. In order to test whether bank A is indeed the price-leader, we perform raw Granger causality tests on daily

[43] While in 2004-2007 bank B closed 48 mortgages with a variable rate annually on average, in 2008 it sold $4,250$, growing steeply to $8,100$ in 2009 and $20,330$ in 2010. Over the same years, bank B's sales of NHG-backed mortgages with a 10-year maturity dropped to 86 in 2009 and 118 in 2010, whereas on average it closed about $3,250$ 10-year mortgage contracts anually in 2004-2007.

averages of mortgage rates with a 10-year maturity per provider over the full sample period.[44] Mortgage rates are commonly set once per week, by each provider on a different day of the business week, typically on a bank-specific fixed day.[45] The following vector-autoregressive (VAR) model is estimated for each bank pair (i, j) between banks A to H

$$\begin{aligned}\begin{pmatrix} r_{i,t} \\ r_{j,t} \end{pmatrix} &= \begin{pmatrix} \alpha_{0,i} \\ \alpha_{0,j} \end{pmatrix} + \begin{pmatrix} \alpha_{i,1,11} & \alpha_{i,1,12} \\ \alpha_{j,1,21} & \alpha_{j,1,22} \end{pmatrix} \begin{pmatrix} r_{i,t-1} \\ r_{j,t-1} \end{pmatrix} + \dots \\ &+ \begin{pmatrix} \alpha_{i,\tau,11} & \alpha_{i,\tau,12} \\ \alpha_{j,\tau,21} & \alpha_{j,\tau,22} \end{pmatrix} \begin{pmatrix} r_{i,t-\tau} \\ r_{j,t-\tau} \end{pmatrix} + \begin{pmatrix} \epsilon_{i,t} \\ \epsilon_{j,t} \end{pmatrix}, \end{aligned} \tag{10}$$

where τ is the number of lags $1 - 5$.

Table 7.1: Granger causality test pairwise VAR models, 10-year daily rates

	r_A	r_B	r_C	r_D	r_E	r_F	r_G	r_H
r_A	$\times$	38.31***	43.44***	59.77***	47.54***	32.03***	55.50***	30.08***
r_B	6.15	$\times$	16.71***	34.12***	23.67***	5.62	23.56***	28.08***
r_C	8.92	19.86***	$\times$	20.30***	24.38***	20.14***	43.40***	15.65***
r_D	13.60**	51.81***	56.20***	$\times$	47.11***	32.08***	75.98***	22.04***
r_E	19.26***	21.48***	46.96***	74.40***	$\times$	34.46**	37.26***	31.30***
r_F	6.70	13.54**	24.92***	28.04***	35.27***	$\times$	33.43***	14.45**
r_G	4.94	16.77***	34.22***	20.94***	23.85***	18.99***	$\times$	16.83***
r_H	12.53**	32.89***	17.67***	47.52***	32.54***	10.27*	28.95***	$\times$

Notes: Chi-squared values; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

Table 7.1 shows Chi-squared values of the null hypothesis that the interest rate in a certain row does not Granger-cause the interest rate in the column. For example, the value in the first row, second column (38.31), represents the Chi-squared value on the test that r_A does not Granger-cause r_B, which is rejected: bank A Granger-causes the interest rate set by bank B. For most interest rate pairs, Granger-causality cannot be rejected, which reflects that each of the interest rates comoves and responds to underlying cost factors. However, while Granger-causality cannot be rejected from bank A's rate to any other bank's, it is rejected from most other banks' rates to bank A's. Furthermore, the Chi-squared value associated with Granger-causation from bank A to other banks is always higher than the other way around, which is not the case for any of the other mortgage providers.

[44] The non-stationarity of the mortgage rates time-series may suggest testing for Granger causality in first differences. However, Toda and Yamamoto (1995) establish that Granger causality can be inferred from non-stationary data that features cointegration on levels. Applied to first differences, results are less pronounced, but still point at bank A as the price-leader.

[45] This is confirmed in interviews with bankers: interest rates are set roughly once a week. De Haan and Sterken (2011) also find that "bank A" always adjusts prices on the same weekday. This pattern is consistent with our data, as daily first differences appear to jump on given days and change less for the rest of the week—bank A changing its mortgage rates mostly on Fridays.

With the factors listed in Table 5.1 added as controls to regression (10), the test results are less pronounced—as expected, in part because the cost factors codetermine each other and all the rates—but still gives highest likelihood to bank A Granger-causing the other banks' rates. The same is true for the inclusion of the average rate of the other banks than the pair compared, to control for their pricing. The pattern also holds in an eight-way simultaneous estimation, and when including additional terms (between 8 and 10) by the Schwartz information criterion. We conclude that bank A is most likely the price-leader.

The pairwise VAR models also allow inference of the lags by which the price-followers respond to the price-leader. The lag τ in $\alpha_{A,\tau,22}$ that is most significant implies that bank C responds after one day to bank A's rate, bank G after two days, banks B, D and E after three days, and banks F and H after five days, *i.e.*, a full business week. While these differences in lags allow in principle for sequential pricing among the followers, there is no indication that there was—nor would it be obvious why a follower bank, and which, would be leading in following. Therefore, assuming that the followers determine their rates simultaneously, after observing the rate of bank A, is appropriate.

It follows that of the eight banks that had a presence in the Dutch mortgage market with a 5% market share or more, the largest five, after bank A (Rabobank), were almost surely under a price leadership ban: B (ING), C (AEGON), D (ABN AMRO), and E and F (SNS, Fortis or ABN AMRO subsidiary). Quite likely, bank G was a Rabobank subsidiary, leaving only one substantial free fringe competitor: bank H (Argenta). This is well within the conditions required in Proposition 2 for full coordination.

Indeed, almost all the banks more often price higher than bank A after May 2009: banks B to G on average 54% of all business days after, against 44% before. The others price higher than Rabobank's minimum rate on the day 92% after, against 86% before. Price dispersion (average daily standard deviation) decreased by 5 to 10%—where the average mortgage rate increased. That these differences are not more pronounced can have several causes. The formulation of the commitment to the European Commission provided for occasional undercutting, as long as no structural price fighter role was taken by the bank under a ban. Variances in the rate averages are large. Adherence to the bans would have been monitored primarily on the advertised rates, leaving some room for individually negotiated discounts. In particular, there is some heterogeneity in the window rates between Rabobank cooperative's local branches, despite central guidance from headquarters.

Price following behavior is expected to increase markedly, and the responsiveness of follower-banks to common cost changes to decrease. Bank H (Argenta) was most likely not under a ban and is therefore expected to respond to the bans differently from the other providers in the sample. It priced significantly below bank A before and after May 2009. If bank H was a formidable fringe follower, the change in S_l would be relatively small. In that case, bank H is expected to also respond more to bank A's rate and less to common costs, but considerably less strongly so than the other followers. If bank H did not constitute much of a competitive threat to the incumbent banks, its responsiveness may also have decreased.

The distribution of the market shares changed only somewhat before and after May 2009, skewing it further toward the incumbent banks. The largest providers each gained market share: bank A from 17 to 20%, bank B from 9 to 14%, banks C and D from 5 to 9%. Together, the largest five providers increased their share from about 55% to almost 70%, at the expense of the remaining fringe competition.

8 Model Calibration and Predictions

The model is calibrated in Section 8.1 to obtain insight on the order of magnitude of the effects of the bans on best-responses in Section 8.2. With bank A as the price-leader, B to D of roughly similar size, and providers E/F and G as likely subsidiaries of banks under a ban, we analyze competition amongst six banks: the price-leader (A) plus five symmetric followers (f), of which four come under a price leadership ban. We consider two alternative post-ban regimes: full coordination and duopoly competition between the leader, together with its ban-pegged followers, and the remaining (representative) free fringe follower (ff). The competitive duopoly equilibrium rates are referred to as $r_A^{PLB_f}$ $(= r_f^{PLB_f})$ and $r_{ff}^{PLB_f}$.

Note that, because of symmetric product differentiation and no capacity constraints, the duopoly model is likely to deliver stronger than actual remaining competitive pressure, so that its predictions on the effects of the bans are lower bounds. Ignoring the free fringe altogether, the fully coordinated equilibrium provides an upper bound. The few fringe banks may have been tolerated to price freely, to be perceived as a price fighter, and steal some market share. They could also have been less responsive due to higher funding costs, or have realized that they were better off refraining from undercutting the price-leader. That is, tacit full collusion could have become an equilibrium, once competition between the other main providers was eliminated by the bans.

8.1 Equilibrium Fit

In competitive equilibrium with $n = 6$, $r_A^* = 4.5$ slightly undercut by $r_f^* = 4.48$, for $c_A = 4.30$, $c_f = 4.32$, which is consistent with the average base interest rate plus risk premium, for parameter values: $a = 6$, $b = 1$, $d = 10$, and $s = .1$. Demand system (1) then represents weekly sales in hundreds and is elastic. The price-leader (each follower) has a markup over costs of 4.6% (3.8%) on a share of total mortgages sold of 48% (10%). The leader has a 10% higher operational profit than its followers, enough to cover substantial information costs. The three largest providers have a joint market share of almost 70% yet, due to symmetry, the market share of the next largest competitors is somewhat higher, and that of the rest somewhat lower, in equilibrium than actual.

Under the price leadership bans, despite about 75 basis points lower funding costs ($c_A = 3.5$, c_f may have decreased less) $r_A^{PLB} = 4.75$ ($= r_f^{PLB}$) in full coordination. The bans are binding the followers, since Proposition 2 applies and the cost difference is small enough for them to want to price below r_A^{PLB}.[46] Market shares hardly change: at equal prices, the leader serves exactly half of the market. Competitive rates but-for the price leadership bans also depend on the funding cost level of the followers in the post-crisis period. They remain well below 4%, however, even if c_f decreases considerably less than c_A. All providers benefit from the bans: the leader's markup increases to 35.7%, that of the followers to 33.8%. Overcharges are almost 100 basis points, or over 25%.

In this baseline parameter specification, the duopoly ($n = 2$) coordinated regime with remaining fringe competition (PLB_f), an average equilibrium mortgage rate at 4.75% ($r_A^{PLB_f} = 4.65 = r_f^{PLB_f}$, $r_{ff}^{PLB_f} = 4.85$) only obtains for higher cost levels, since margins are lower. The leader and ban-pegged followers need to have operated jointly at $c_A = 4$, and $c_{ff} = 4.8$. Relatively high funding costs are required, in part because remaining competition is stronger than actual in the symmetric model. In duopoly equilibrium, the fringe follower maintains a market share of just below 10% and barely breaks even, while the leader has a good 15% overcharge. The average margin increase is 33 basis points and the overcharge 7.6%.

8.2 Predicted Responses

Between these two calibrated equilibrium bounds, we can analyze best-responses. A first prediction, that we however cannot independently test, is that in competition the rates of all banks are most sensitive to changes in their own marginal funding costs.[47] The effects of cost changes on the rates of the followers that are under a ban is reversed: through the leader's responses, each of them responds much stronger than in competition to changes in the leader's cost (from near zero to (nearly) one half) and no longer to changes in their own costs (from near one half to zero). This is true, independent of the strength of fringe competition.

Figure 3 plots $B_{f,1}$, S_A and S_f as functions of s for the competitive ($n = 6$), duopoly ($n = 2$) and monopoly ($B_{f,1} = 1$) scenario's. The elasticities T_A and T_f are not plotted: at these equilibrium rate changes, they correlate nearly perfectly with S_A and S_f at a level just slightly (about 0.04) below.[48] The baseline specification is on the vertical dashed line ($s = .1$).

[46] For the baseline specification, $r_f^* \left(r_A^{PLB}\right) \leq r_A^{PLB}$ for $c_f \leq 0.59c_A + 2.48$.

[47] In the baseline model, $\frac{dr_A^*}{dc_A} = .468$ and $\frac{dr_f^*}{dc_f} = .513$, while $\frac{dr_A^*}{dc_f} = .084$ and $\frac{dr_f^*}{dc_A} = -.056$.

[48] In the calibrated model, for the monopoly limit values $d = 0$ (irrespective of n): $H_A = .478$ and $H_f = .482$, with a direct effect in the latter of .434.

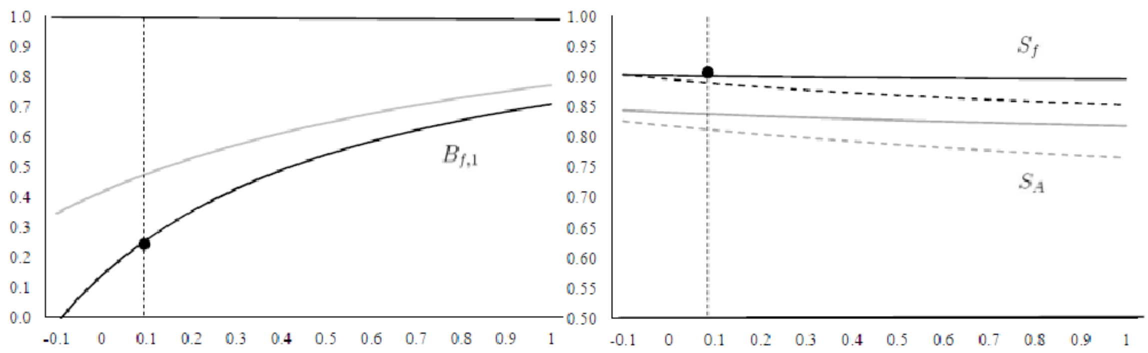

Figure 3: As a function of s for $n = 6$ (black, baseline) and $n = 2$ (gray, fringe): left-hand panel $B_{i \neq l,1}$ and right-hand panel $S_{i \neq l}$ (solid) and S_l (dashed).

In the left-hand panel, the value of $B_{f,1}$ is small but positive for values of s around zero, that is, when the variances of the common and idiosyncratic demand shock are similar, so that the leader's rate is not a very informative signal. It remains below three-quarters also when s goes to its upper bound. In the competitive baseline, $B_{f,1} = .259$, increasing in s to .709 for $s = 1$. Hence, the responsiveness of the follower-banks increases by close to fourfold for followers under a ban.

The right-hand panel shows the effect of common cost shocks. S_A (dashed lines) decreases in s but remains in the upper quartile. In competition, $S_A = .468 + 5 \times .084 = .890$ and $S_f = .671 + .259 \times .890 = .901$. Under binding bans, both decrease to $\frac{1}{2}$, entirely through the leader's rate (*i.e.*, $S_f^d = 0$). The elasticities of mortgage rates to marginal funding costs decrease even more: in competition they are $T_A^* = .853$ and $T_f^* = .867$, and both decrease to .368 under fully coordinating bans.

With remaining fringe competition ($n = 2$), the banks under a ban mimic the leader, but the free fringe stays competitive, which constrains the leader. The representative fringe competitor bank responds in the baseline specification by $B_{ff1} = .477$—a value increasing in s to maximally .773 when $s = 1$. Its increase in responsiveness is thus expected to be only about half of that of the banks bound by a ban. S_A, and therefore S_f for the followers under a ban, decreases by a mere 9% (to .812), as the leader's responsiveness to the fringe follower's cost decreases only slightly.[49] S_{ff} decreases only 7% (to .838), and also both $T_{ff} = .813$ and $T_A = .778 = T_f^{PLB}$ stay high. The large difference in predictions between the full coordination and the fringe competition scenario reflects that the symmetric model does not capture well that the free fringe remained small and constrained pricing little.

Table 8.1 collects the testable predictions on changes in responsiveness from the introduction of the price leadership bans.

[49] The increase in $\frac{dr_A}{dc_f}$ per follower in case some fringe competition remains is strong (from .084 to .332), compared to the decrease when bank A obtains full monopoly power (from .084 to 0).

Table 8.1: Predicted best-response changes

		before	after imposition of the bans					
			full coordination	$\frac{\text{after-before}}{\text{before}}$ (%)	fringe ($n = 2$)		$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	
S_A		.890	$\frac{1}{2}$	-44	.812		-9	
T_A		.853	.368	-57	.758		-11	
$B_{f,1}$	$B_{ff,1}$	.259	1	285	1	.477	285	84
S_f^d	S_{ff}^d	.671	0	-100	0	.451	-100	-33
S_f	S_{ff}	.901	$\frac{1}{2}$ ($= S_A$)	-44	.812 ($= S_A$)	.838	-10	-7
T_f	T_{ff}	.867	.368 ($= T_A$)	-58	.778 ($= T_A$)	.813	-10	-6

We conclude that indicative of the price leadership ban's restricting competition in the Dutch mortgage market are: (i) a 10 to 60% decrease in the price-leader's pass-through ($S_A > T_A$), depending on the strength of the fringe competition; (ii) a fourfold increase in the responsiveness of the rates of the follower-banks under a ban to the leader's rate ($B_{f,1}$), irrespective of any remaining competition; (iii) a 10 to 60% decrease in the pass-through of the price-followers under a ban ($S_f > T_f$), depending on the strength of the fringe competition; and (iv) still a doubling of the responsiveness to the leader's rate of free fringe providers ($B_{ff,1}$), yet hardly a change to their pass-through ($S_{ff} > T_{ff}$). If the main banks' direct rate responses and their cost pass-through measures (at least) halve with the introduction of the bans, this is indicative of a weak competitive fringe.

9 Price Leadership Regime Shift

In Section 9.1, we first consider the pricing behavior of price-leader bank A—including in the log-linear specification to estimate T_A. In Section 9.2, the responses of the seven largest price-followers are estimated as pairwise relationships between the rate of bank A and their rates. Section 9.3 repeats the analyses on daily averages of 10-year maturity mortgages, which is the most sold NHG-backed mortgage product. While the baseline estimations on individual mortgages across all maturities exploits the largest possible number of independent observations in the NHG data set, the 10-year sample allows for standard cointegration tests. Section 9.4 presents regressions in first differences of response adjustment of short-run deviations from the estimated long-run equilibrium best-response functions.

9.1 Leader Responses

Bank A's rate is expected to be determined by a linear combination of cost factors that include its own costs and that of its followers

$$r_{A,j,m,t} = \beta_{A,m,0} + \boldsymbol{\beta}_{A,2}\mathbf{C}_{m,t} + \left(\beta_{A,0}^{PLB} + \boldsymbol{\beta}_{A,2}^{PLB}\mathbf{C}_{m,t}\right) D_{A,t}^{PLB} + \epsilon_{A,j,m,t}, \tag{11}$$

where $r_{A,j,m,t}$ is the interest rate set by bank A on individual mortgage j, with maturity m at day t.

Maturity fixed effects $\beta_{A,m,0}$ adjust for unobserved variation over mortgage types, resulting, for example, from different contract clauses, household characteristics, demand elasticity and shifters. While these may have changed over the sample period, for example due to the crisis and ensuing changes in regulation and attitudes toward borrowing, these would not have happened as a result of, and certainly not (all) simultaneously with, the imposition of the bans. We therefore only interact the common constant $\beta_{A,0}^{PLB}$ with the ban-dummy ($D_{A,t}^{PLB}$).[50]

Vector $\mathbf{C}_{m,t}$ contains 10 explanatory variables per maturity m. These include nine cost controls: CDS spreads for the biggest five mortgage providers in the Netherlands (matched by maturity), two base rates (Eonia and the interbank swap rate with maturity matched to the mortgage), the rate on Dutch deposits, and the amount of Tier 1 equity capital to the value risk-weighted assets. $Tier1$ is included to control for possible costs of capital requirements in compliance with Basel III, which was relevant in anticipation from 2010. In addition, market concentration is controlled for using a monthly HHI (between 0 and 1), based on the total volume of NHG mortgages sold per provider in a given month. The timing of the ban-dummy is determined by a Quandt-Andrews test.

Table 9.1 gives the relevant regression results of model (11) in the left-hand column, before, and the change after, over the whole sample with interaction—so that the total effect is the sum.[51]

Table 9.1. Regression results bank A's rate to costs, individual rates

	price-leader response		log-specification	
break date	01-03-2009 (495.346)		01-07-2009 (404.355)	
	before	$\times D_{A,t}^{PLB}$	before	$\times D_{A,t}^{PLB}$
$\mathbf{C}_{m,t}$ (S_A)	1.846*** (.017)	−.987*** (.027)	×	×
HHI	.031*** (.002)	−.022** (.002)	.040*** (.004)	−.009* (.005)
$\ln \mathbf{C}_{m,t}$ (T_A)	×	×	.898*** (.015)	−.522*** (.021)
N	176442		176442	
R^2	.6262		.6536	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

Bank A's pricing behavior changed structurally around Spring 2009.[52] S_A is the sum of the coefficients in $\boldsymbol{\beta}_{A,2}$ to the cost factors in $\mathbf{C}_{m,t}$, which are all individually

[50] When all maturity fixed effects are interacted with the ban-dummy, estimation results are similar in sign and magnitude for all banks, except bank B—which my be due to its substitution from 10-year to variable mortgages, which Rabobank did not sell. The baseline findings are confirmed in the 10-year maturity, the best-seller by far (55.5%)—see Section 9.5. Results are robust also to exclusion of maturity fixed effects.

[51] The full tables of baseline regression results are given in Appendix G.

[52] The F-values to all estimated break dates reported in the following far surpass the critical F-test

significant. It has a low accumulated standard error. The absolute value being larger than one reflects colinearity, yet its strong decrease (53%) after the bans took effect is highly significant, consistent with fully coordinated price leadership by bank A. This suggests that little fringe competition remained on the Dutch mortgage credit market after the crisis, favoring the full coordination model. Note that the effect of the HHI becomes even less important after the break date—even though its average value increases from .078 to .110. The maturity fixed effects are small, significant, and do not form a discernible pattern. The relevant results are robust to their exclusion.

The right-hand column in Table 9.1 gives the results of estimating the log-version of model (11),

$$\ln r_{A,j,m,t} = \beta'_{A,m,0} + \boldsymbol{\beta}'_{A,2} \ln \mathbf{C}_{m,t} + \left(\beta_{A,0}^{PLB\prime} + \boldsymbol{\beta}_{A,2}^{PLB\prime} \ln \mathbf{C}_{m,t}\right) D_{A,t}^{PLB\prime} + \epsilon_{A,j,m,t}, \quad (12)$$

which returns the cost pass-through elasticity, T_A, as the sum of cost coefficients in $\boldsymbol{\beta}'_{A,2}$. July 1, 2009 is found to be the most likely moment of a break in cost pass-through by bank A. The value of T_A is close to unity before the price bans were introduced, consistent with competitive price leadership. It decreases by 58% to .376, which is very close to the baseline prediction for full coordination. $T_A < S_A$ and also decreases somewhat more relatively, as predicted. These findings are indicative of coordinated price leadership by Rabobank with little or no remaining fringe competition, after the bans took effect.

9.2 Follower Responses

The equilibrium best-response of each of the seven largest price-following banks (B to H) to the mortgage rate set by bank A is pair-wise estimated as

$$\begin{aligned} r_{f,j,m,t} &= \beta_{f,m,0} + \beta_{f,1} r_{A,m,t-\tau} + \boldsymbol{\beta}_{f,2} \mathbf{C}_{m,t} \\ &\quad + \left(\beta_{f,0}^{PLB} + \beta_{f,1}^{PLB} r_{A,m,t-\tau} + \boldsymbol{\beta}_{f,2}^{PLB} \mathbf{C}_{m,t}\right) D_{f,t}^{PLB} + \epsilon_{f,j,m,t}, \end{aligned} \quad (13)$$

where $r_{f,j,m,t}$ is the mortgage rate set on mortgage j of follower bank $f = B, \ldots, H$ with maturity m at day t, and $r_{A,m,t-\tau}$ is the average rate set by the price-leader on the matching maturity at day $t - \tau$. Hence, τ represents the number of days that it takes the price-following bank to respond (1-5 days) identified in Section 7.[53]

Maturity fixed effects are captured in $\beta_{f,m,0}$, estimated over the full sample period. The coefficients on the interest rate set by bank A, β_1 and β_1^{PLB} are not expected to differ between maturities, so that we can obtain a single estimate for the behavior

values of the numbers of observations we analyze. The estimated value for H_A in the log-specification remains almost the same if its break date is fixed at March 1st instead. Also, all the relevant results are nearly identical when taking May 1st as a fixed dummy moment.

[53] Choosing the lags for all followers the same ($\tau = 3$) does not materially affect the results, which is further support to the assumption that price-followers set their rates simultaneously.

of follower banks to bank A's interest rate.[54] $\mathbf{C}_{m,t}$ is the 10×7 matrix of control variables, for each of the seven price-following banks included in the regression. Cost factors were matched by the maturity of the mortgage where possible, *i.e.*, for CDS spreads and the interbank swap rates.[55]

The moment of the follower-specific ban-dummy $D^{PLB}_{f,t}$ is expected to be in or around Spring 2009. The main coefficient of interest is $\beta^{PLB}_{f,1}$, which measures the difference in response of the price-follower f to the interest set by the price-leader A before and after imposition of the price leadership ban. We expect these coefficients to be positive and significantly different from zero for all price-following banks, as the theory predicts that the interest rates of the followers respond more to the price leader's rate in a coordinated than in a competitive market. More specifically, we expect $\beta_{f,1} + \beta^{PLB}_{f,1}$ to be close to 1, and $\beta_{f,1}$ relatively small. Any free fringe follower (bank H) would follow bank A's interest rate much less closely—with the smaller the bank, the weaker the following. To a common cost shock, we expect all the followers' responses (S_f) to decrease—the competitive fringe less so.

The relevant results of regression (13) are in Table 9.2. The pricing behavior of followers B to F structurally changes in Spring 2009, between mid-February and mid-June, consistent with the price leadership bans coordinating mortgage rates.[56] Bank G changed its behavior more gradually between the start of the financial crisis until July 2009: there is no pronounced global maximum F-value. There is also no distinct break for bank H, which is consistent with our conjecture that it is Argenta. For better comparison to the other banks, we continue to analyze banks G and H before and after May 1st.[57]

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Table 9.2: Interest best-response results follower-banks' to bank A's rate and costs, individual rates

In the period before the price leadership bans, the effect of bank A's rate ($\beta_{f,1}$) is positive for all followers, and significant for all but bank C, ranging from close to

[54] As established in Section 7, the set of price-followers almost surely includes all the banks under an explicit price leadership ban, as well as at least one smaller free fringe follower bank (most likely bank H). However, note that failure to include all mortgage providers active in the market has no bearing on the pairwise results.

[55] The overnight Eonia, deposit and Tier1/RWA rates do not differ by maturity. Matching the HHI left too few datapoints for certain infrequent maturities in certain months.

[56] The results are robust to slight changes in the break dates in and around Spring 2009. We also performed a robustness test with the break date for all banks set at March 1, 2009, the day on which the price-leadership was found to have changed in model (11). This gave similar results for the follower responses.

[57] The Quandt-Andrews test establishes breaks at 18-11-2008 for bank G and 29-1-2008 for bank H, but the F-values for these dates do not have a distinct maximum. Using these break dates in the estimations gave similar results.

Table 9.2: Interest best-response results follower-banks' to bank A's rate and costs, individual rates

	$r_{B,j,m,t}$	$r_{C,j,m,t}$	$r_{D,j,m,t}$	$r_{E,j,m,t}$	$r_{F,j,m,t}$	$r_{G,j,m,t}$	$r_{H,j,m,t}$
response time	3	1	3	3	5	2	5
break date	16-06-09	13-02-09	04-03-09	03-03-09	27-05-09	01-05-09	01-05-09
	(686.990)	(581.596)	(243.678)	(310.731)	(75.591)		
$r_{A,m,t-\tau}$	.095***	.024	.206***	.116***	.133***	.169***	.122***
	(.018)	(.016)	(.022)	(.010)	(.009)	(.011)	(.006)
$r_{A,m,t-\tau} \times D_{f,t}^{PLB}$	.231***	.504***	.635***	.472***	.391***	.376***	−.331***
	(.056)	(.017)	(.023)	(.013)	(.019)	(.016)	(.030)
$\mathbf{C}_{m,t}$ (S_f^d)	1.970***	1.883***	1.654***	1.663***	1.620***	1.688***	1.437***
	(0.060)	(0.037)	(0.051)	(0.029)	(0.028)	(0.032)	(0.094)
$\mathbf{C}_{m,t} \times D_{f,t}^{PLB}$	−2.994***	−1.852***	−1.504***	−1.777***	−.844***	−1.693***	−.998***
	(.148)	(.044)	(.060)	(.042)	(.073)	(.059)	(.240)
HHI	.092***	.039***	.057***	.036***	.050***	.005	.110***
	(.004)	(.003)	(.004)	(.003)	(.002)	(.003)	(.003)
$HHI \times D_{f,t}^{PLB}$	−.101***	.030***	−.040***	−.029***	−.021***	−.005	−.115***
	(.005)	(.006)	(.005)	(.003)	(.005)	(.003)	(.003)
maturity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	56088	59767	62540	55230	57255	46485	32939
R^2	.4551	.6835	.5591	.6807	.6514	.6211	.6811

Notes: Response time in days. Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

zero to .206. After the bans became effective, $\beta^{PLB}_{f,1}$ is significantly positive at the 1%-level for all followers except bank H, that had not come under a ban. It is small for bank B, which may reflect that its business focus had shifted to variable rate mortgages, which bank A did not sell. All signs of the combined cost coefficients are in the expected direction and statistically significant.[58]

The common cost effects S^d_f are all larger than one in absolute value. HHI is a significant but small explanatory variable, the effect of which becomes smaller for all banks but bank C after the bans.[59] The variance inflation factors confirm multicollinearity between the different cost factors—yet on the interest rate of the price-leader the VIF remains below 10 for all regressions.[60]

Bank H, likely the only provider not under a ban, behaved markedly different from the banks under a ban. Its responsiveness to the leader's rate in fact *de*creases with the introduction of the bans, whereas the theory only predicts a much lower increase in responsiveness, relative to the other followers, in case bank H constituted a serious competitive threat. Bank H does change its responsiveness to common cost changes in the expected direction and less pronounced than the other banks. Its somewhat maverick behavior, undercutting the other banks with less regards to cost and the leader's pricing, while gaining little market share, seems consistent with bank H being perceived as only a weak competitor—which the findings on S_A also suggest.

The main results are not sensitive to the selection of the response period.[61] Qualitatively comparable results are also found if the offer date instead of the date of closure of a mortgage is used at the relevant rate-setting moment.[62] The same is true for regressing model (13) on all mortgages of all providers (but bank A) combined, thus including all of any remaining fringe competition.[63]

A standard regression of the log-specification

$$\ln r_{f,j,m,t} = \beta'_{f,m,0} + \boldsymbol{\beta}'_{f,2} \ln \mathbf{C}_{m,t} + \left(\beta^{PLB\prime}_{f,0} + \boldsymbol{\beta}^{PLB\prime}_{f,2} \ln \mathbf{C}_{m,t}\right) D^{PLB\prime}_{f,t} + \epsilon_{f,j,m,t}, \qquad (14)$$

[58] When we add the average interest rate of non-paired banks to regressions (13) and interact it with the dummy, bank A's interest rate is still followed significantly more closely with the bans—albeit somewhat less pronounced. Part of the variance in one price-following bank's interest rate is explained by the rate set by the others responding to one another. Yet all signs remain the same and significant.

[59] The HHI was included in reference to the Dutch competition authority's explanation for the Spring 2009 rate jump (see footnote 4). It is not material to our results, however.

[60] See Appendix E.

[61] Setting $\tau = 0$, we estimated regressions (13) with a same-day response time. The changes in responsiveness to bank A are comparable to the main analysis, also in significance, except for bank B, which has a weaker increase significant at only the 10% level.

[62] Using additional WEW information on offer date and household identify, we were able to identify the offer date of 146,455 observations for the price following banks, or approximately 9 loans made per bank per day.

[63] For this case, sums of parameters (all signifcant at 1%-level) $\beta_{f,1} + \beta^{PLB}_{f,1}$ also increase strongly, by .38 to .42 from .15 to .27. The sum of cost parameters decreases across the board, from the range of 1.46 to 1.75 to the range of $-.08$ to .10, consistent with the model prediction that remaining fringe competition mitigates the coordinating effect of the bans.

per follower on the full sample before and after a per-bank estimated break date gives the marginal funding cost elasticities of its rate as the sum of cost coefficients in $\boldsymbol{\beta}'_{f,2}$. Those are given in Table 9.3.

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Table 9.3: Standard cost pass-through elasticities for price-follower banks, individual rates

The T_f estimates are significant before and after estimated break dates that are in the expected period. Consistent with competition before the bans were imposed, the values of all followers are close to one (.965 on average, excluding bank H). The lower values after (.372 on average, a 61% decrease), are consistent with market power for bank A, combined with a tighter following by the banks under a ban. T_H decreases strongly, consistent with bank H's maverick role.

The equilibrium effect through r_A^* that is ignored in estimations (14) is partly picked up by the cost parameter estimates that underlie the results in Table 9.3. It is likely to be substantial, since the cost factors of the followers and the leader are highly correlated. Including $\ln r_{A,m,t-\tau}$ as a control variable in regressions (14) results in lower estimates of the sum of the direct cost effects, T_f' (by .142 before and .280 after, on average), which is consistent with the direct effects $\beta_{f,1} \times T_A$ (of .111 on average before and .210 after, excluding bank H). The break dates remain all around Spring 2009. This more sophisticated approach provides a better fit and is more appropriate, given that price leadership is the mode of competition in this market.

Table 9.4 contains the main results of a selection of banks, including the constructed values of S_f, for easy comparison to the numerical predictions in Table 8.1.[64]

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Table 9.4: Realized best-response results follower banks' B, C, D, and H to leader bank A's rate and costs, individual rates

Follower banks B to G changed their behavior consistent with theory. The interest rate of bank A became much more important to the price following banks under a ban, with the sums of the coefficients increasing even over the predicted fourfold. While banks B and C were not very responsive to bank A's rate before, after the bans they are close followers—despite bank B obtaining more market share in variable mortgages after Spring 2009. For all follower-banks, both S_f^d and S_f decrease significantly, indicating that the importance of cost changes to price under the bans is reduced, as expected. Both absolute values and relative changes are much larger

[64] See Appendix H for comparisons of all the banks.

Table 9.3: Standard cost pass-through elasticities for price-follower banks, individual rates

	$r_{B,j,m,t}$		$r_{C,j,m,t}$		$r_{D,j,m,t}$		$r_{E,j,m,t}$	
break date	28-02-09 (917.079)		9-09-08 (493.132)		01-07-09 (288.853)		23-01-09 (551.645)	
	before	$\times D^{PLB}_{B,t}$	before	$\times D^{PLB}_{C,t}$	before	$\times D^{PLB}_{D,t}$	before	$\times D^{PLB}_{E,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	.969***	−1.595***	.959***	−.641***	1.156***	−.419***	.883***	−.538***
	(.025)	(.035)	(.026)	(.030)	(.031)	(.021)	(.015)	(.023)
N	107729		70165		67569		63375	
R^2	.460		.607		.537		.769	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

	$r_{F,j,m,t}$		$r_{G,j,m,t}$		$r_{H,j,m,t}$	
break date	30-05-09 (100.925)		24-07-09 (395.329)		03-01-09 (1255.428)	
	before	$\times D^{PLB}_{F,t}$	before	$\times D^{PLB}_{G,t}$	before	$\times D^{PLB}_{H,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	.912***	−.022	.911***	−.342***	.862***	−1.365***
	(.021)	(.046)	(.015)	(.039)	(.020)	(.051)
N	62636		51353		49455	
R^2	.663		.726		.718	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

Table 9.4: Realized best-response results follower banks' B, C, D, and H to leader bank A's rate and costs, individual rates

	$r_{B,j,m,t}$			$r_{C,j,m,t}$			$r_{D,j,m,t}$			$r_{H,j,m,t}$		
	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)
$B_{f,1}$	.095	.326	243	.024	.528	2100	.206	.841	308	.122	−.209	−271
S_f^d	1.970	−1.024	−152	1.883	.031	−98	1.654	.150	−91	1.437	.439	−69
S_f	2.145	−.744	−134	1.927	.485	−74	2.034	.872	−57	1.662	.259	−84
T_f	.969	−.626	−165	.959	.318	−67	1.156	.737	−36	.862	−.503	−158
T_f'	.701	−1.305	−286	.996	.180	−82	.876	.482	−45	.789	.199	−75

than predicted by the linear model, yet the patterns are consistent. For some banks (B and E), S_f^d even becomes slightly negative. As predicted, $S_f > S_f^d$ while the relative change in S_f is somewhat smaller, and $S_f > T_f$ for all followers. The pattern of change is consistent with the price leadership bans' fully coordinating the mortgage rates and a weak competitive fringe.

9.3 10-year Maturity

Most new contracts in the sample (55.5%) have a 10-year maturity, which is the mortgage type we consider separately in this section. Bank A is the largest seller, whereas it did not offer variable rate mortgages. Therefore, even though with only about 10% of observations in each regression results will have less power than for all maturities, in the 10-year maturity alone we expect a stronger effect from the change in bank A's price leadership role.

Market concentration is somewhat larger than average: the HHI was .079 and .110 on average before and after March 1, 2009. We consider daily average rates, to reduce cross-sectional variance—such as bank B hardly selling this maturity in the years 2009-2010. The break dates are determined anew using the Quandt-Andrews test.

For bank A, regressing model (11) on 10-year maturity (m =10-year) daily average rates establishes a structural break on February 28, 2009 ($F = 312.473$), after which S_A decreases from 2.116*** (.040) by 1.300*** (.073).[65] The marginal cost elasticity of mortgage rates breaks earlier, November 25, 2008, with the T_A-values decreasing from 1.167*** (.044) by .869*** (.053). These decreases, by 61% and 74%, again indicate weak fringe competition.

For the followers, Table 9.5 present the associated results of the interest response estimation of model (13).

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Table 9.5: Interest best-response results follower banks' to bank A's rate and costs, 10-year daily averages

All follower-banks except bank H respond structurally more strongly to the rate of bank A in the period early January to end of May 2009. The estimates of $B_{f,1}$ are positive, significantly different from zero, and substantially larger for all banks under a ban in 10-year maturity than across all contracts. In particular, bank B's following behavior is strongly affected in this product. The responsiveness of most follower-banks to bank A's interest rate close to tripled. For all banks in the sample (except H), the coefficients $\beta_{f,1}$ are small in competition and increase to close to one, in accordance with the theory. The common cost shock responses all decrease

[65] The full tables of 10-year maturity regression results are given in Appendix I.

Table 9.5: Interest best-response results follower banks' to bank A's rate and costs, 10-year daily averages

	$r_{B,t}$	$r_{C,t}$	$r_{D,t}$	$r_{E,t}$	$r_{F,t}$	$r_{G,t}$	$r_{H,t}$
response time	3	1	3	3	5	2	5
break date	13-01-09	26-01-09	04-03-09	24-2-09	27-05-09	06-01-09	14-01-08
	(31.514)	(27.858)	(61.707)	(72.984)	(70.824)	(17.182)	(18.439)
$r_{A,t-\tau}$	.385***	.386***	.422***	.245***	.238***	.278***	.260***
	(.045)	(.060)	(.041)	(.038)	(.028)	(.061)	(.033)
$r_{A,t-\tau} \times D^{PLB}_{f,t}$	.187***	.418***	.585***	.629***	.633***	.529***	−.224**
	(.110)	(.069)	(.058)	(.058)	(.059)	(.074)	(.144)
$\mathbf{C}_t$ (S^d_f)	1.109***	1.295***	1.518***	1.373***	1.575***	1.757***	1.228***
	(.142)	(.158)	(.102)	(.095)	(.075)	(.156)	(.328)
$\mathbf{C}_t \times D^{PLB}_{f,t}$	−1.615***	−1.616***	−1.569***	−1.502***	−1.043***	−1.594***	−.786
	(.278)	(.170)	(.119)	(.128)	(.141)	(.177)	(.448)
HHI	.018***	−.009**	.015***	.030***	.006***	−.009***	.038***
	(.004)	(.004)	(.003)	(.003)	(.002)	(.003)	(.004)
$HHI \times D^{PLB}_{f,t}$	−.038***	−.024***	−.033***	−.053***	−.025***	−.006	−.042***
	(.006)	(.005)	(.004)	(.004)	(.003)	(.004)	(.008)
N	1657	1957	2205	2162	2217	2125	1626
R^2	.802	.816	.872	.876	.874	.745	.500

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

according to theory. Bank H again behaves independently without constituting much as a competitive threat.[66] The standard cost pass-through elasticity estimates for the follower-banks are all significant at the 1%-level before and after the estimated break dates, and decrease strongly: from close to unity, by 50 to 75%, to values consistent with the full coordination model. We conclude that pricing in the 10-year maturity daily averages changes even more pronounced in support of the theory than in the analyses of all observations combined.

9.4 Response Adjustments

The 10-year maturity estimation results allow for cointegration tests on their residuals. These show pairwise cointegration between the rates of the leader and the followers.[67] This suggests analysis of short-run response adjustments to the linear level relations estimated above. While the equilibrium price-leadership model does not offer guidance on the signs and magnitudes of these adjustments, a fast return would support our equilibrium approach in levels. In addition, stronger responses in first differences of the price-followers' mortgage rates to the rate of the leader from the break dates would also be consistent with the regime shifts.

For the 10-year maturity only, we take the first differences from equation (13) for each follower bank: $\Delta r_{f,t} = r_{f,t} - r_{f,t-5}$, differencing the rate on day t with that of one week before.[68] This difference is regressed on the latest rate adjustment of bank A that is relevant for follower f: $\Delta r_{A,t-\tau}$, with τ the number of days that it takes bank f to respond (1-5 days). That is, we pair-wise estimate

$$\begin{aligned} \Delta r_{f,t} \;=\;& \gamma_{f,0} + \gamma_{f,1}\Delta r_{A,t-\tau} + \boldsymbol{\gamma}_{f,2}\Delta \mathbf{C}_t \\ & + \left(\gamma_{f,0}^{PLB} + \gamma_{f,1}^{PLB}\Delta r_{A,t-T} + \boldsymbol{\gamma}_{f,2}^{PLB}\Delta \mathbf{C}_t\right) D_{f,t}^{PLB} \\ & + \theta_f \epsilon_{f,t-5} + \varepsilon_{f,t}, \end{aligned} \tag{15}$$

in which the cost factors are similarly expressed as weekly differences and $\epsilon_{f,t-5}$ is the one business week-differences error term derived from the cointegrating equilibrium equation. The break dates are as determined above.

[66] Repeating the 10-year maturity type estimations with individual mortgages as the unit of measurement gave comparable results, which are somewhat in-between those presented in Table 9.2 (all mortgage types, individual observations) and Table 9.5 (10-year maturity, daily average rates). Except bank B's responsiveness to bank A's rate no longer increases significantly different from zero, which may again be explained by bank B's moving out of 10-year mortgages and into variable mortgages instead, which bank A did not sell.

[67] Cointegration test results are given in Appendix I.3.

[68] Each bank tends to adjust its rate on a given day of the business week, so that expected price variance over weekdays between weekly price jumps is small except on the day of the price jump. By comparing each day's interest rate to last week's interest rate, weekly changes in interest rates will be measured for each weekday, and misspecification of the response time to bank A's interest rate will affects the results less. Note that we estimated day-to-day first differences for robustness to similar results.

The main coefficient of interest is θ_f, which can be interpreted as the speed of adjustment (in weeks) toward the long-run equilibrium. It should have a value between zero and -1 (full return to equilibrium within a week)—with, for example $-.7$ implying return within two weeks. Fast adjustment lends further support to our equilibrium model. Coefficients $\gamma_{f,1}^{PLB}$ can provide further indication of how much closer bank A is followed after the imposition of the price leadership bans. It is expected to be positive for all banks, except H.

The relevant results of regression (15) are in Table 9.6.[69]

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Table 9.6: Response adjustment results follower-banks' rate to bank A's rate and costs, 10-year daily averages

The values of θ_f are significant at the 1%-level and lie between $-.699$ and $-.922$, so that adjustment to the long-run relation is fast: within one to two weeks. The coefficients $\gamma_{f,1}^{PLB}$ are positive, sizable compared to $\gamma_{f,1}$ and significant for all followers, except bank B, which got out of 10-year mortgages around the price leadership bans, and bank H, which did not operate under a price leadership ban.

Analoguously, we estimate short-run adjustment to equilibrium in all maturities combined.[70] This is non-standard, since the full sample features cross-sectional variance as well as variance over time. First differences to the week-average show a similarly fast return to equilibrium: θ_f values are significant between $-.434$ and $-.743$). All followers respond much weaker than in levels to bank A's rate before the bans, yet in first differences also the price-leader is followed several times more closely after imposition of the price leadership bans. The estimates of $\gamma_{f,1}^{PLB}$ are significant and multiple times the responses before for all banks C to G again.

We separately tested for asymmetry between up- and downward price movements, but found no significant difference, which should also not be expected on the basis of the theory. Adjustments to common cost shock differences all decrease—except for bank B and H, for which the changes are not significant. The effects of ΔHHI are significant but small. We conclude that the response adjustment results validate the equilibrium best-response approach and support our findings of the price leadership bans affecting pricing.

10 But-for Mortgage Rates

The regressions results allow some insight into what may have been the mortgage rates, but for the imposition of the price leadership bans. Setting $D_{A,t}^{PLB} = 0$ in (11) from the estimated break date March 1, 2009 forward, the daily mortgages rates that

[69] The full table of results is given in Appendix I.4.

[70] The full analysis and results are given in Appendix J.

Table 9.6: Response adjustment results follower-banks' rate to bank A's rate and costs, 10-year daily averages

	$\Delta r_{B,t}$	$\Delta r_{C,t}$	$\Delta r_{D,t}$	$\Delta r_{E,t}$	$\Delta r_{F,t}$	$\Delta r_{G,t}$	$\Delta r_{H,t}$
response time	3	1	3	3	5	2	5
break date	13-01-09	26-01-09	04-03-09	24-02-09	27-05-09	06-01-09	14-01-08
$\Delta r_{A,t-\tau}$	.146***	.273***	.180***	.131***	.133***	.137***	.124***
	(.037)	(.065)	(.035)	(.029)	(.028)	(.073)	(.039)
$\Delta r_{A,t-\tau} \times D^{PLB}_{f,t}$	.114	.064***	.287***	.302***	.423***	.168***	−.436
	(.078)	(.080)	(.066)	(.063)	(.087)	(.110)	(.226)
$\epsilon_{f,t-5}$	−.790***	−.870***	−.753***	−.699***	−.819***	−.899***	−.922***
	(.038)	(.033)	(.029)	(.034)	(.033)	(.032)	(.071)
$\Delta \mathbf{C}_t$ (combined)	.266	.521	.441	.394*	.694**	.880***	.801
	(.447)	(.480)	(.271)	(.207)	(.276)	(.264)	(.493)
$\Delta \mathbf{C}_t \times D^{PLB}_{f,t}$	−.208	−.658	−.499	−.337	−.739**	−1.262***	1.050
	(.765)	(.493)	(.324)	(.294)	(.371)	(.403)	(.965)
other controls	ΔHHI	ΔHHI	ΔHHI	ΔHHI	ΔHHI	ΔHHI	ΔHHI
N	1472	1957	2125	2056	2168	1980	1335
R^2	.399	.452	.392	.359	.415	.360	.458

Notes: Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

Rabobank would have set in competitive price leadership can be calculated from the estimated parameters and values of the explanatory variables. Using this rate and the parameters found for each follower-bank to (13), with $D_{f,t}^{PLB} = 0$ from the later bank-specific break dates onwards, we can predict what would have been that bank's competitive offers in response.

Table 10.1 summarizes the estimated average but-for mortgage rate and overcharge per type until the end of the sample period.[71] The but-for rates are consistent with the calibrated model. The overcharges found suggest full coordination. Across all mortgage types and banks, the average overcharge is 125 basis points or 26%, on average. Bank H's overcharge is even larger. Nearly identical overcharges result from comparing estimated, rather than observed, actual rates to the but-for rates.

Table 10.1: Predictions of but-for mortgage rates

	bank A			average B to G			overall average		
	but-for	overcharge		but-for	overcharge		but-for	overcharge	
		bp.	%		bp.	%		bp.	%
var	2.85	79.93	19.69	2.77	90.93	26.28	2.78	89.36	25.34
1-5	2.86	87.68	23.22	3.16	95.94	22.26	3.12	94.76	22.40
5	2.93	124.06	29.44	3.34	82.11	20.87	3.28	88.11	22.10
5-10	3.30	114.49	25.46	3.43	113.48	24.46	3.41	113.62	24.60
10	3.42	136.43	28.41	3.50	125.58	27.31	3.49	127.13	27.47
>10	3.65	142.70	27.64	3.66	138.03	26.86	3.66	138.70	26.97
all	3.44	136.25	28.17	3.48	123.10	25.62	3.47	124.97	25.99

Notes: Overcharges are expressed as percentage of actual rate.

In the 10-year maturity estimated in isolation, but-for rates are lower (2.77 to 3.46) and overcharges are substantially higher (134 to 200 basis points, 28 to 42%) than in the baseline model, which may reflect that but-for estimations for longer-term fixed-rate contracts should probably be corrected more for refinancing risk rewards.

These values are only indicative, as a number of caveats apply. The linear model may not capture all the complexities of actual bank funding. The full vector of cost components was included in each regression as controls, rather than to approximate actual total marginal funding costs, while RMBS was excluded yet relevant. Also, the funding portfolio constitutions were likely changed after the financial crisis, possibly also structurally. In particular, it is possible refinancing risks increased after the crisis, when the banks may have been tempted to use more short-term over longer-term funding, as short-term rates in particular were kept low by monetary policy with an uncertain time horizon. To the extent that the banks did not fully maturity match or hedge their longer term mortgage contracts, they would have priced in the perceived risk of refinancing costs rising during the mortgage period. In hindsight, funding costs may have stayed lower longer than originally expected. Projecting but-for rates without taking such relevant expectations, for which we have no proxy

[71] The underlying estimates per follower bank are provided in Appendix K.

available, fully into account can overestimate overcharges by a chance factor that partly is a risk reward. Indeed, we find higher overcharges on the longer maturities.

11 Concluding Remarks

In a bespoke model, and using unique data, we find strong evidence that price leadership bans imposed by the European Commission on all main mortgage providers but Rabobank in the Spring of 2009 shifted the market from a competitive to a collusive barometric price leadership equilibrium. Our empirical findings are consistent, both in sign and magnitude, with the model predictions. The baseline specification is a fitting calibration. The price-leader's pass-through elasticity (T_A) decreases by 58%, while the responsiveness of the rates of the follower-banks under a ban to the leader's rate ($B_{f,1}$) on average increased over fourfold, and their pass-through (S_f, T_f) decreased over 75%. The differences are highly significant in all maturities combined, and even stronger in the 10-year mortgage contracts alone.

Not rising risk premiums, nor diminished foreign fringe competition, but stalled banking competition is the main explaination for the sudden high mortgage rates in the Low Countries. Before the price leadership bans, Rabobank would set its rate close to funding costs under the competitive pressure of being undercut by its main rivals. After imposition of the bans, all providers but an insignificant free fringe closely followed the lead rate of Rabobank upward, while funding costs ceased to be important. Indicative estimates of but-for mortgage rates and overcharges are substantial and in further support of the model.

The must-follow price-leader role of Rabobank is also consistent with the brief period of low margins during the NMa's initial investigation: September 2010 to May 2011. At that time, by not passing through the rising funding costs into its mortgage rates, Rabobank would force reduced margins, even losses, on all banks banned from pricing above. Interestingly, only the margins on mortgages with a variable mortgage rate, which is the only mortgage type that Rabobank did not carry, remained high during the 'NMa study-dip'.

Structural breaks in pricing behavior are estimated robustly around the Spring of 2009, when the price leadership bans were collectively negotiated—over six months after the fall of Lehman Brothers. The bans had taken effect, even though they were not strictly legally binding until after the formal State aid decision dates in November 2009 and early 2010, so that during the preceding months, undercutting would not yet have been directly punishable as a State aid violation.[72] This is a normal

[72] The Dutch competition authority dismissed the bans twice as a possible explanation for the mortgage rates rise, on the argument that the price rise occurred before the State aid decisions were formally given. In NMa (2011) and again—after the investigation had been reopened because of our preliminary finding that margin had risen again—in ACM, *Concurrentie op the Hypotheekmarkt: Een Update van de Margeontwikkelingen sinds begin 2011*, April 2013. Remarkably, in October 2009 NMa warned the Commission that the concentrated Dutch market would be "locked" with a price

duration for the internal processing and signing of a formal Commission decision, however. The "commitment concerning price leadership" had effectively been imposed in April 2009.[73] In the mean time, the aided banks would not have wanted to poach Rabobank's market share aggressively, as this was exactly the Commission's concern and doing so would have further tightened restructuring and divestiture requirements. If at all necessary to assure early adherence to the bans, in retaliation Rabobank could have threatened to stop leading altogether, which would have exposed the banks under a ban to the risk of unintentionally violating their State aid conditions.[74]

Alternatively, the ban negotiations themselves may have facilitated coordination. They framed Rabobank's role as a price-leader to aid coordination on a focal point. Remarkably, several years later, after the bans were (partially and sequentially) lifted, mortgage rates in the Netherlands still remained relatively high compared to other EMU countries.[75] Tighter regulation and stricter market access requirements from the Dutch Central Bank in response to the crisis created a significant barrier to entry. The incumbents may well have been able to maintain a level of coordination in the mean time, as unprecedented low interest rate levels implied discount factors that may have been high enough to sustain collusion. Since the steep policy rate fall happened simultaneously, the price leadership bans may have simply been a cartel catalyst. Only when entry into the market started to occur, in the Summer of 2015, did the surplus margins on mortgages fade—see Figure 2. In State aid control, which is the European Commission's fourth pillar of competition policy, pricing bans are better avoided as a behavioral remedy in highly concentrated markets, where they may chill rather than protect competition.

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ban for ING, and later possibly also ABN AMRO. See Dijkstra *et al.* (2014) for a detailed account.

[73] Judgment of the General Court of March 2, 2012, in *Kingdom of the Netherlands and ING v European Commission*, recital 14.

[74] Theoretically it is possible that Rabobank would have been better off in a simultaneous move uninformed equilibrium, in which the other banks were handicapped by the price leadership bans. The bans would then have forced Rabobank's competitors to price precautiously high, in order to avoid undercutting any of their rivals in equilibrium—in breach of their bans. Rabobank would set a high price, pushing up its followers' prices. Its unlikely, however, that Rabobank would have benefited from giving up its superior market research department. Moreover, all tests in Section 7 indicate that bank A remained in the lead throughout.

[75] AEGON's ban was no longer under a ban from June 15, 2011, when it had repaid the aid. ING's price leadership ban was lifted for the Netherlands in a revised Commission Decision of November 16, 2012, State Aid SA.33305 (2012/C) and SA.29832 (2012/C) implemented by Netherlands for ING, recital 112. A ban for SNS remained a possibility until the end of 2013. ABN AMRO's was lifted in April 2014.

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A Solutions to the Model

In Section $A1.1$, the competitive equilibrium with $n-1$ followers is characterized. In Section $A1.1.1$, the model is first fully solved for all followers being identical. In Section $A1.1.2$, the best-response functions for the case of heterogenous follower-banks that are used in the main text are derived by analogy. Section $A1.3$ identifies the conditions under which the leader-follower roles are stable in equilibrium. Section $A1.4$ characterizes the equilibrium with a price leadership ban.

A.1 Competitive Equilibrium

Without loss of generality, let $l = 1$ with costs c_l, and let each follower have its own individual costs c_i, for $i = 2, ..., n$, which are common knowledge. Let $\mathbf{c}_{i \neq l} = (c_2, ..., c_n)$. The profits of firm i with type $t = \{l, f\}$ are

$$\pi_i = (r_i - c_i)\, V \left(a_t - br_i + d \left(\frac{1}{n} \sum_{j=1}^{n} r_j - r_i \right) \right),$$

in which the value of $a_l = a + e$ is known to the leader, who invested in obtaining this information, but the followers can only form expectations about their $a_f = a - e$. V is the monetary value of the mortgage type, depending on the interest and the financed sum and the length of the fixed interest rate-period (maturity). Without loss of generality, we set $V = 1$.

The leader sets it price optimally first at r_l^*, to be analyzed later. Since apart from the value of a en e, the games is common knowledge, the followers can extract the value of $a + e$ from observing r_l^* and (knowing $\overline{a}$) form conditional expectations

$$E[a - \overline{a} | a - \overline{a} + e] = \frac{(a - \overline{a} + e)\sigma_a^2}{\sigma_a^2 + \sigma_e^2} \text{ and } E[e | a - \overline{a} + e] = \frac{(a - \overline{a} + e)\sigma_e^2}{\sigma_a^2 + \sigma_e^2},$$

from which follows that their

$$\begin{aligned} E\left[a_f | a + e\right] &= E\left[a - e | a - \overline{a} + e\right] = E\left[a | a - \overline{a} + e\right] - E\left[e | a - \overline{a} + e\right] \\ &= E[a - \overline{a} | a - \overline{a} + e] + \overline{a} - E[e | a - \overline{a} + e] \\ &= \overline{a} + (a - \overline{a} + e)s \text{ in which } s = \frac{\sigma_a^2 - \sigma_e^2}{\sigma_a^2 + \sigma_e^2}. \end{aligned}$$

As it turns out, the equilibrium price of the leader is linear in the following components

$$r_l^* = \frac{a+e}{A} - \frac{B}{A} f\left(\mathbf{c}_{i\neq l}\right) - \frac{C}{A} c_l - \frac{D}{A}, \tag{16}$$

in which $f\left(\mathbf{c}_{i\neq l}\right)$ is a function and A, B, C and D are constants made precise below. Hence, the followers can distill that

$$a - \overline{a} + e = Ar_l^* + Bf\left(\mathbf{c}_{i\neq l}\right) + Cc_l + D - \overline{a}$$

and the signal r_l^* is interpreted as

$$\begin{aligned} E\left[a_f | a+e\right] &= \overline{a} + (a - \overline{a} + e)s \\ &= \overline{a} + \left(Ar_l^* + Bf\left(\mathbf{c}_{i\neq l}\right) + Cc_l + D - \overline{a}\right) s. \end{aligned}$$

Then

$$\begin{aligned} E\left[a_f | a+e\right] &= \left(Ar_l^* + Bf\left(\mathbf{c}_{i\neq l}\right) + Cc_l\right) s + (1-s)\,\overline{a} + Ds \\ &= Asr_l^* + Bsf\left(\mathbf{c}_{i\neq l}\right) + Csc_l + E \text{ in which } E = (1-s)\,\overline{a} + Ds. \end{aligned}$$

Given this expectation, the followers move simultaneously after bank l, so we first consider the equilibrium prices between the followers for any value of r_l. Follower $i \neq l$ maximizes expected profits, after observing r_l, that is

$$\max_{r_{i\neq l}} E\left[\pi_{i\neq l}\right] = \left(r_{i\neq l} - c_{i\neq l}\right)\left(Asr_l + Bsf\left(\mathbf{c}_{i\neq l}\right) + Csc_l + E - br_{i\neq l} + d\left(\frac{1}{n}\sum_{j=1}^{n} r_j - r_{i\neq l}\right)\right).$$

This provides $n-1$ first-order conditions, one for each follower $i \neq l$:

$$\frac{d\pi_{i\neq l}}{dr_{i\neq l}} = Asr_l + Bsf\left(\mathbf{c}_{i\neq l}\right) + Csc_l + E - 2br_{i\neq l} + \frac{d}{n}\left(\sum_{j=1}^{n} r_j + r_{i\neq l}\right) - 2dr_{i\neq l} + c_{i\neq l}\left(b + \frac{n-1}{n} d\right) = 0. \tag{17}$$

which solve as a subgame perfect equilibrium amongst the followers.

A.1.1 Symmetric Followers

In case all followers have the same costs c_f, $f(\mathbf{c}_{i\neq l}) = c_f$ and the followers subgame has a symmetric equilibrium at price r_f. The system (17) simplifies to

$$Asr_l + Bsc_f + Csc_l + E - 2br_f + \frac{d}{n}\left(\sum_{i=1}^{n} r_j + r_f\right) - 2dr_f + c_f\left(b + \frac{n-1}{n}d\right) = 0 \tag{18}$$

or, since by switching the isolated r_f with r_l in the summation

$$\frac{1}{n}\left(\sum_{i=1}^{n} r_j + r_f\right) = \frac{1}{n}nr_f + \frac{1}{n}r_l = r_f + \frac{r_l}{n},$$

$$E - (2b+d)\,r_f + \left(\frac{d}{n} + As\right) r_l + c_f\left(b + \frac{n-1}{n}d + Bs\right) + Csc_l = 0.$$

This solves as

$$r_f^* = \frac{E + \left(\frac{d}{n} + As\right) r_l + c_f\left(b + \frac{n-1}{n}d + Bs\right) + Csc_l}{2b+d}. \tag{19}$$

The leader-bank l sets its rate r_l, knowing the values of a and e, and taking the followers equilibrium responses into account, that is by maximizing profit

$$\begin{aligned}
\pi_l &= (r_l - c_l)\left(a + e - br_l + d\left(\frac{n-1}{n}r_f + \frac{1-n}{n}r_l\right)\right) = \frac{r_l - c_l}{n}\left((a+e)\,n + (n-1)\,dr_f + (d - (b+d)\,n)\,r_l\right) \\
&= (r_l - c_l)\left(a + e - br_l + d\left(\frac{n-1}{n}\left(\frac{E + \left(\frac{d}{n} + As\right) r_l + c_f\left(b + \frac{n-1}{n}d + Bs\right) + Csc_l}{2b+d}\right) + \frac{1-n}{n}r_l\right)\right),
\end{aligned}$$

to r_l. From setting the derivative

$$\begin{aligned}
\frac{d\pi_l}{dr_l} &= a + e - 2br_l + d\left(\frac{n-1}{n}\left(\frac{E + 2\left(\frac{d}{n} + As\right) r_l + c_f\left(b + \frac{n-1}{n}d + Bs\right) + Csc_l}{2b+d}\right) + 2\frac{1-n}{n}r_l\right) \\
&\quad + c_l b - c_l d\frac{(n-1)\left(\frac{d}{n} + As\right)}{n\,(2b+d)} - c_l d\frac{1-n}{n}
\end{aligned} \tag{20}$$

equal to zero follows

$$\begin{aligned}
r_l^* &= (a+e)\frac{n^2(2b+d)}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)} \\
&+\frac{dn(n-1)E}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)} \\
&+\frac{2b^2n^2-2d^2n+d^2n^2+d^2+3bdn^2-2bdn-Adn^2s+Cdn^2s+Adns-Cdns}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)}c_l \\
&+\frac{d(n-1)(bn-d+dn+Bns)}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)}c_f.
\end{aligned} \tag{21}$$

As alluded to, the structure of the leader's best-response function is indeed the linear form (16) which identified conditional expectations. Therefore, implicit definitions of A, B, C and D are obtained from equating (21) and (16) as:

$$\begin{aligned}
A &= \frac{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)}{n^2(2b+d)} \\
B &= -\frac{d(n-1)(bn-d+dn+Bns)A}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)} \\
C &= -\frac{(2b^2n^2-2d^2n+d^2n^2+d^2+3bdn^2-2bdn-Adn^2s+Cdn^2s+Adns-Cdns)A}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)} \\
D &= -\frac{dn(n-1)EA}{2(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn)}
\end{aligned}$$

These solve, using the definition $E=(1-s)\,\overline{a}+Ds$, as:

$$
\begin{aligned}
A &= \frac{-4d^2n+4b^2n^2+2d^2n^2+2d^2+6bdn^2-4bdn}{2bn^2+dn^2+2dn^2s-2dns}\\
B &= -\frac{-2d^2n+d^2n^2+d^2+bdn^2-bdn}{2bn^2+dn^2+dn^2s-dns}=-\frac{(n-1)\left((n-1)\,d+bn\right)d}{n\,(2bn+dn-ds+dns)}\\
C &= -\frac{(2b+d)\left(-2d^2n+2b^2n^2+d^2n^2+d^2+3bdn^2-2bdn\right)}{(2bn+dn-ds+dns)\,(2bn+dn-2ds+2dns)}\\
D &= \frac{\overline{a}\,(d-dn-ds+dns)}{2bn+dn-ds+dns}=\frac{\overline{a}d\,(1-n)\,(1-s)}{(2b+d)\,n-d\,(1-n)\,s}\\
E &= \frac{(2b+d)\,(1-s)\,\overline{a}n}{2bn+dn-ds+dns}
\end{aligned}
\tag{22}
$$

These allow for making the best-response function explicit as

$$
\begin{aligned}
r_f^* &= \frac{\frac{(2b+d)(1-s)\overline{a}n}{2bn+dn-ds+dns}+\left(\frac{d}{n}+\frac{-4d^2n+4b^2n^2+2d^2n^2+2d^2+6bdn^2-4bdn}{2bn^2+dn^2+2dn^2s-2dns}s\right)r_l+c_f\left(b+\frac{n-1}{n}d-\frac{-2d^2n+d^2n^2+d^2+bdn^2-bdn}{2bn^2+dn^2+dn^2s-dns}s\right)}{2b+d}\\
&\quad-\frac{\frac{(2b+d)\left(-2d^2n+2b^2n^2+d^2n^2+d^2+3bdn^2-2bdn\right)}{(2bn+dn-ds+dns)(2bn+dn-2ds+2dns)}sc_l}{2b+d},
\end{aligned}
$$

which beautifies into

$$
r_f^*=\frac{n\overline{a}\,(1-s)}{(2b+d)\,n+d\,(n-1)\,s}+\frac{d+(2bn+2d\,(n-1))\,s}{(2b+d)\,n+2d\,(n-1)\,s}r_l+\frac{bn+(n-1)\,d}{(2b+d)\,n+d\,(n-1)\,s}c_f-\frac{\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2\right)s}{((2b+d)\,n+d\,(n-1)\,s)\,((2b+d)\,n+2d\,(n-1)\,s)}c_l. \tag{23}
$$

Then

$$
r_l^*=\frac{(a+e)\,n^2\,(2b+d)+dn\,(n-1)\,E+\left(2b^2n^2-2d^2n+d^2n^2+d^2+3bdn^2-2bdn-Adn^2s+Cdn^2s+Adns-Cdns\right)c_l+d\,(n-1)\,(bn-d+dn+Bns)\,c_f}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)},
$$

from which it follows that

$$
r_l^*=\frac{n\,(2bn+dn+2dns-2ds)}{4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2}\left(a+e-\frac{\overline{a}d\,(n-1)\,(s-1)}{2bn+dn-ds+dns}+\frac{(2b+d)\left(4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2\right)}{2\,(2bn+dn-ds+dns)\,(2bn+dn-2ds+2dns)}c_l+\frac{d\,(n-1)\,(bn+d\,(n-1))}{2bn^2+dn^2+dn^2s-dns}c_f\right). \tag{24}
$$

The combination (24) and (23) with $r_l=r_l^*$ in (23) indeed satisfies the two first-order conditions (18) plus (20), and so $\left(r_l^*,r_f^*\right)$ constitute the unique Nash equilibrium of this game.

A.1.2 Asymmetric Followers

In case each follower have its own individual costs c_i, for $i=2,...,n$, the followers subgame is asymmetric and the solution of $n-1$ equations, for each $i\neq l$, the first order condition is:

$$
Asr_l+Bsf\left(\mathbf{c}_{i\neq l}\right)+Csc_l+E-2br_{i\neq l}+\frac{d}{n}\left(\sum_{j=1}^{n}r_j+r_{i\neq l}\right)-2dr_{i\neq l}+c_{i\neq l}\left(b+\frac{n-1}{n}d\right)=0,
$$

so that

$$r_{i\neq l} = \frac{Asr_l + E + \left(b + \frac{n-1}{n}d\right)c_{i\neq l} + Bsf\left(\mathbf{c}_{i\neq l}\right) + Csc_l + \frac{d}{n}\sum_{j\neq i}^{n} r_j}{2\left(b + \frac{n-1}{n}d\right)},$$

which can be rewritten as

$$2\left(b + \frac{n-1}{n}d\right)r_{i\neq l} - \frac{d}{n}\sum_{j\neq i\neq l}^{n} r_j = E + \left(\frac{d}{n} + As\right)r_l + Csc_l + \left(b + \frac{n-1}{n}d\right)c_{i\neq l} + Bsf\left(\mathbf{c}_{i\neq l}\right) \text{ for } i = 2, ..., n$$

in which $\sum_{j\neq i\neq l}^{n} r_j$ is the sum of all mortgage rates except that of bank l and follower-bank i considered.

We can write this system of $n-1$ first-order conditions in matrix notation as

$$\begin{bmatrix} 2\left(b+\frac{n-1}{n}d\right) & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} \\ -\frac{d}{n} & 2\left(b+\frac{n-1}{n}d\right) & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} \\ -\frac{d}{n} & -\frac{d}{n} & \dots & -\frac{d}{n} & -\frac{d}{n} \\ -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & 2\left(b+\frac{n-1}{n}d\right) & -\frac{d}{n} \\ -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & 2\left(b+\frac{n-1}{n}d\right) \end{bmatrix} \begin{bmatrix} r_2 \\ r_3 \\ \dots \\ r_{n-1} \\ r_n \end{bmatrix} = \begin{bmatrix} E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_2 + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_3 + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ \dots \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_{n-1} + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_n + Bsf\left(\mathbf{c}_{i\neq l}\right) \end{bmatrix}.$$

So

$$\begin{bmatrix} r_2^* \\ r_3^* \\ \dots \\ r_{n-1}^* \\ r_n^* \end{bmatrix} = \begin{bmatrix} 2\left(b+\frac{n-1}{n}d\right) & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} \\ -\frac{d}{n} & 2\left(b+\frac{n-1}{n}d\right) & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} \\ -\frac{d}{n} & -\frac{d}{n} & \dots & -\frac{d}{n} & -\frac{d}{n} \\ -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & 2\left(b+\frac{n-1}{n}d\right) & -\frac{d}{n} \\ -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & -\frac{d}{n} & 2\left(b+\frac{n-1}{n}d\right) \end{bmatrix}^{-1} \begin{bmatrix} E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_2 + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_3 + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ \dots \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_{n-1} + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_n + Bsf\left(\mathbf{c}_{i\neq l}\right) \end{bmatrix}$$

$$= \frac{1}{(2b+d)(2bn-d+2dn)} \begin{bmatrix} d+2bn+dn & d & d & d & d \\ d & d+2bn+dn & d & d & d \\ d & d & \dots & d & d \\ d & d & d & d+2bn+dn & d \\ d & d & d & d & d+2bn+dn \end{bmatrix} \begin{bmatrix} E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_2 + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_3 + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ \dots \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_{n-1} + Bsf\left(\mathbf{c}_{i\neq l}\right) \\ E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_n + Bsf\left(\mathbf{c}_{i\neq l}\right) \end{bmatrix}.$$

Hence, for example

$$r_2^* = \frac{(d+2bn+dn)\left(E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_2 + Bsf\left(\mathbf{c}_{i\neq l}\right)\right) + d\left(E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_3 + Bsf\left(\mathbf{c}_{i\neq l}\right) + \dots\right)}{(2b+d)(2bn-d+2dn)},$$

which generalizes by analogy to the symmetric case to

$$r_{i\neq l}^* = \frac{(d+2bn+dn)\left(E + \left(\frac{d}{n}+As\right)r_l + Csc_l\right) + (d+2bn+dn)\left(b+\frac{n-1}{n}d\right)c_{i\neq l} + (d+2bn+dn)\,Bsf\left(\mathbf{c}_{i\neq l}\right) + d\,(n-2)\,Bsf\left(\mathbf{c}_{i\neq l}\right) + d\sum_{k\neq i\neq l}^{n}\left(E + \left(\frac{d}{n}+As\right)r_l + Csc_l + \left(b+\frac{n-1}{n}d\right)c_k\right)}{(2b+d)(2bn-d+2dn)},$$

which, since

$$\sum_{k\neq i\neq l}^{n}\left(E+\left(\frac{d}{n}+As\right)r_l+Csc_l+\left(b+\frac{n-1}{n}d\right)c_k\right)=(n-2)\left(E+\left(\frac{d}{n}+As\right)r_l+Csc_l\right)+\left(b+\frac{n-1}{n}d\right)\sum_{k\neq i\neq l}^{n}c_k,$$

and

$$(d+2bn+dn)\,Bsf\left(\mathbf{c}_{i\neq l}\right)+d\,(n-2)\,Bsf\left(\mathbf{c}_{i\neq l}\right)=(2bn-d+2dn)\,Bsf\left(\mathbf{c}_{i\neq l}\right)$$

can be written as

$$\begin{aligned} r^*_{i\neq l} &= \frac{(2bn+2dn-d)\left(E+\left(\frac{d}{n}+As\right)r_l+Csc_l\right)+(d+2bn+dn)\left(b+\frac{n-1}{n}d\right)c_{i\neq l}+(2bn-d+2dn)\,Bsf\left(\mathbf{c}_{i\neq l}\right)+d\left(b+\frac{n-1}{n}d\right)\sum_{k\neq i\neq l}^{n}c_k}{(2b+d)(2bn-d+2dn)} \\ &= \frac{E+\left(\frac{d}{n}+As\right)r_l+Csc_l+\frac{b+\frac{n-1}{n}d}{2bn-d+2dn}\left((d+2bn+dn)\,c_{i\neq l}+d\sum_{k\neq i\neq l}^{n}c_k\right)+Bsf\left(\mathbf{c}_{i\neq l}\right)}{2b+d} \end{aligned} \tag{25}$$

Note indeed that if all followers have the same costs $c_f=f\left(\mathbf{c}_{i\neq l}\right)$ we get (19):

$$r^*_{i\neq l}=\frac{E+\left(\frac{d}{n}+As\right)r_l+Csc_l+\left(b+\frac{n-1}{n}d+Bs\right)c_f}{2b+d}=r^*_f.$$

Next, to find the constant values A, B, C, D and E, consider that leader-bank l sets its rate r_l, knowing the values of a and e, and taking the followers equilibrium responses into account—that is by maximizing profit

$$\begin{aligned} \pi_l &= (r_l-c_l)\left(a+e-br_l+d\left(\frac{1}{n}\sum_{j\neq l}^{n}r_j+\frac{1-n}{n}r_l\right)\right) \\ &= (r_l-c_l)\left(a+e+\left(\frac{1-n}{n}d-b\right)r_l+\frac{d}{n}\sum_{j\neq l}^{n}\frac{E+\left(\frac{d}{n}+As\right)r_l+Csc_l+\frac{b+\frac{n-1}{n}d}{2bn-d+2dn}\left((d+2bn+dn)\,c_{j\neq l}+d\sum_{k\neq j\neq l}^{n}c_k\right)+Bsf\left(\mathbf{c}_{i\neq l}\right)}{2b+d}\right) \\ &= (r_l-c_l)\left(a+e-\left(b-d\frac{1-n}{n}-d\frac{n-1}{n}\frac{\left(\frac{d}{n}+As\right)}{2b+d}\right)r_l+d\frac{n-1}{n}\frac{E}{2b+d}+d\frac{n-1}{n}\frac{Cs}{2b+d}c_l+d\frac{n-1}{n}\frac{Bsf\left(\mathbf{c}_{i\neq l}\right)}{2b+d}+\frac{d\,(bn-d+dn)}{n^2(2b+d)(2bn-d+2dn)}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j+d\sum_{k\neq j\neq l}^{n}c_k\right)\right) \end{aligned}$$

which again reduces to the symmetric case for all followers' costs equal to c_f.

Setting the derivative

$$\begin{aligned} \frac{d\pi_l}{dr_l} &= a+e-2\left(b-d\frac{1-n}{n}-d\frac{n-1}{n}\frac{\left(\frac{d}{n}+As\right)}{2b+d}\right)r_l+d\frac{n-1}{n}\frac{E}{2b+d}+d\frac{n-1}{n}\frac{Bsf\left(\mathbf{c}_{i\neq l}\right)}{2b+d} \\ &\quad+\frac{d\,(bn-d+dn)}{n^2(2b+d)(2bn-d+2dn)}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j+d\sum_{k\neq j\neq l}^{n}c_k\right)+c_l\left(d\frac{n-1}{n}\frac{Cs}{2b+d}+b-d\frac{(n-1)\left(\frac{d}{n}+As\right)}{n(2b+d)}-d\frac{1-n}{n}\right) \end{aligned}$$

equal to zero obtains

$$\begin{aligned}\left(2b-2d\frac{1-n}{n}-d\frac{n-1}{n}\frac{2\left(\frac{d}{n}+As\right)}{2b+d}\right)r_l &= a+e+d\frac{n-1}{n}\frac{E}{2b+d}+d\frac{n-1}{n}\frac{Bsf\left(\mathbf{c}_{i\neq l}\right)}{2b+d}\\ &+c_l\left(d\frac{n-1}{n2}\frac{Cs}{2b+d}+b-d\frac{(n-1)\left(\frac{d}{n}+As\right)}{n\,(2b+d)}-d\frac{1-n}{n}\right)\\ &+\frac{d\,(bn-d+dn)}{n^2\,(2b+d)\,(2bn-d+2dn)}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j+d\sum_{k\neq j\neq l}^{n}c_k\right)\end{aligned}$$

so that

$$\begin{aligned}r_l^* &= (a+e)\frac{n^2\,(2b+d)}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}+\frac{dn\,(n-1)\,E}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}\\ &+\frac{dn\,(n-1)\,Bsf\left(\mathbf{c}_{i\neq l}\right)}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}+\frac{2b^2n^2-2d^2n+d^2n^2+d^2+3bdn^2-2bdn-Adn^2s+Cdn^2s+Adns-Cdns}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}c_l\\ &+\frac{d\,(bn-d+dn)}{2\,(2bn-d+2dn)\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j+d\sum_{k\neq j\neq l}^{n}c_k\right)\end{aligned} \tag{26}$$

which is the same equilibrium structure and identical to (21) if all followers operated under c_f.

Note that

$$\begin{aligned}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j+d\sum_{k\neq j\neq l}^{n}c_k\right) &= (d+2bn+dn)\sum_{j\neq l}^{n}c_j+d\sum_{j\neq l}^{n}(j-2)\,c_j\\ &= \sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j+d\,(j-2)\,c_j\right)\\ &= \sum_{j\neq l}^{n}(2bn+dn+(j-1)\,d)\,c_j,\end{aligned}$$

which makes the case exactly the same as the symmetric case by taking "$j=n$":

$$\sum_{j\neq l}^{n}(2bn+dn+(j-1)\,d)\,c_f=(n-1)\,(2bn+dn+(n-1)\,d)\,c_f=(n-1)\,(2bn-d+2dn)\,c_f.$$

Take

$$f\left(\mathbf{c}_{i\neq l}\right)=\frac{\sum_{j\neq l}^{n}(2bn+dn+(j-1)\,d)\,c_j}{(n-1)\,(2bn-d+2dn)}\ \text{ or }\ \sum_{j\neq l}^{n}(2bn+dn+(j-1)\,d)\,c_j=(n-1)\,(2bn-d+2dn)\,f\left(\mathbf{c}_{i\neq l}\right),$$

so that indeed $f\left(\mathbf{c}_{i\neq l}\right)=c_f$ if all banks have the same cost c_f.

$$\begin{aligned}r_l^* &= (a+e)\frac{n^2\,(2b+d)}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}+\frac{(bn-d+dn+Bns)\,d\,(n-1)}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}f\left(\mathbf{c}_{i\neq l}\right)\\ &+\frac{2b^2n^2-2d^2n+d^2n^2+d^2+3bdn^2-2bdn-Adn^2s+Cdn^2s+Adns-Cdns}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}c_l+\frac{dn\,(n-1)\,E}{2\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2-Asdn^2+Asdn\right)}\end{aligned}$$

From the structure (16) follow implicit definitions of A, B, C and D that resolve as the same expressions as in (22) for the symmetric case above. Substituting these into (25) obtains

$$
\begin{aligned}
r^*_{i\neq l} &= \frac{\frac{(2b+d)(1-s)\bar{a}n}{2bn+dn-ds+dns} + \left(\frac{d}{n} + \left(\frac{-4d^2n+4b^2n^2+2d^2n^2+2d^2+6bdn^2-4bdn}{2bn^2+dn^2+2dn^2s-2dns}\right)s\right)r_l - \frac{(2b+d)\left(-2d^2n+2b^2n^2+d^2n^2+d^2+3bdn^2-2bdn\right)}{(2bn+dn-ds+dns)(2bn+dn-2ds+2dns)}sc_l}{2b+d} \\
&+ \frac{\frac{b+\frac{n-1}{n}d}{2bn-d+2dn}\left((d+2bn+dn)\,c_{i\neq l} + d\sum_{k\neq i\neq l}^{n} c_k\right) - \frac{-2d^2n+d^2n^2+d^2+bdn^2-bdn}{2bn^2+dn^2+dn^2s-dns}s\frac{\sum_{j\neq l}^{n}\left((d+2bn+dn)c_j+d\sum_{k\neq j\neq l}^{n} c_k\right)}{(n-1)(2bn-d+2dn)}}{2b+d} \\
&= \frac{(1-s)\,n\bar{a}}{2bn+dn-ds+dns} + \frac{d+(2bn+2d\,(n-1))\,s}{(2b+d)\,n+2d\,(n-1)\,s}r_l - \frac{\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2\right)s}{(2bn+dn-ds+dns)\,(2bn+dn-2ds+2dns)}c_l \\
&+ \frac{b+\frac{n-1}{n}d}{(2bn-d+2dn)\,(2b+d)}\left((d+2bn+dn)\,c_{i\neq l} + d\sum_{k\neq i\neq l}^{n} c_k - \frac{ds}{2bn+dn-ds+dns}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j + d\sum_{k\neq j\neq l}^{n} c_k\right)\right)
\end{aligned}
\tag{27}
$$

Note that

$$\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j + d\sum_{k\neq i\neq l}^{n} c_k\right) = (2n\,(b+d)-d)\left(c_{i\neq l} + \sum_{k\neq i\neq l}^{n} c_k\right)$$

so that the last component in (27) simplifies as follows:

$$
\begin{aligned}
& \frac{b+\frac{n-1}{n}d}{(2bn-d+2dn)\,(2b+d)}\left((d+2bn+dn)\,c_{i\neq l} + d\sum_{k\neq j\neq l}^{n} c_k - \frac{ds}{(2bn+dn-ds+dns)}\sum_{j\neq l}^{n}\left((d+2bn+dn)\,c_j + d\sum_{k\neq j\neq l}^{n} c_k\right)\right) \\
=\ & \frac{b+\frac{n-1}{n}d}{(2bn-d+2dn)\,(2b+d)}\left((d+2bn+dn)\,c_{i\neq l} + d\sum_{k\neq j\neq l}^{n} c_k - \frac{ds}{(2bn+dn-ds+dns)}\left((2n\,(b+d)-d)\left(c_{i\neq l} + \sum_{k\neq i\neq l}^{n} c_k\right)\right)\right) \\
& \frac{b+\frac{n-1}{n}d}{(2bn-d+2dn)\,(2b+d)}\left(\left((d+2bn+dn) - \frac{ds\,(2n\,(b+d)-d)}{(2bn+dn-ds+dns)}\right)c_{i\neq l} + \left(d - \frac{ds\,(2n\,(b+d)-d)}{(2bn+dn-ds+dns)}\right)\sum_{k\neq i\neq l}^{n} c_k\right) \\
=\ & \frac{(bn-d+dn)\,(d+2bn+dn-2ds+dns)}{(2bn-d+2dn)\,(2bn+dn-ds+dns)}c_{i\neq l} + \frac{d\,(1-s)\,(bn-d+dn)}{(2bn-d+2dn)\,(2bn+dn-ds+dns)}\sum_{k\neq i\neq l}^{n} c_k.
\end{aligned}
$$

Replacing this latter part in (27), the full expression given in the main text is obtained:

$$
\begin{aligned}
r^*_{i\neq l} &= \frac{(1-s)\,n\bar{a}}{2bn+dn-ds+dns} + \frac{d+(2bn+2d\,(n-1))\,s}{(2b+d)\,n+2d\,(n-1)\,s}r_l - \frac{(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2)\,s}{(2bn+dn-ds+dns)\,(2bn+dn-2ds+2dns)}c_l \\
&+ \frac{(bn-d+dn)\,(d+2bn+dn-2ds+dns)}{(2bn-d+2dn)\,(2bn+dn-ds+dns)}c_{i\neq l} + \frac{d\,(1-s)\,(bn-d+dn)}{(2bn-d+2dn)\,(2bn+dn-ds+dns)}\sum_{k\neq i\neq l}^{n} c_k,
\end{aligned}
\tag{28}
$$

which again reduces to (23) for the symmetric followers cost c_f case.

From (16) and using that

$$f\left(\mathbf{c}_{i\neq l}\right)=\frac{c_{i\neq l}+\sum_{k\neq i\neq l}^{n}c_k}{n-1}=\frac{\sum_{i\neq l}^{n}c_i}{n-1},$$

we construct

$$\begin{aligned} r_l^* \;=\; & \frac{n\left(a+e\right)\left(2bn+dn-2ds+2dns\right)}{4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2}-\frac{\bar{a}dn\left(n-1\right)\left(s-1\right)\left(2bn+dn-2ds+2dns\right)}{\left(2bn+dn-ds+dns\right)\left(4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2\right)} \\ & +\frac{2bn+dn}{4bn+2dn-2ds+2dns}c_l+\frac{d\left(bn-d+dn\right)\left(2bn+dn-2ds+2dns\right)}{\left(2bn+dn-ds+dns\right)\left(4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2\right)}\sum_{i\neq l}^{n}c_i, \end{aligned} \tag{29}$$

which if all followers have the same costs $c_f=f\left(\mathbf{c}_{i\neq l}\right)$ reduces to (24).

Hence, in the Nash equilibrium

$$\begin{aligned} r_{i\neq l}^* \;=\; & \frac{\left(1-s\right)n\bar{a}}{2bn+dn-ds+dns}+\frac{d+\left(2bn+2d\left(n-1\right)\right)s}{\left(2b+d\right)n+2d\left(n-1\right)s} \\ & \times\left(\begin{array}{c}\frac{n(a+e)(2bn+dn-2ds+2dns)}{4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2}-\frac{\bar{a}dn(n-1)(s-1)(2bn+dn-2ds+2dns)}{(2bn+dn-ds+dns)\left(4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2\right)} \\ +\frac{2bn+dn}{4bn+2dn-2ds+2dns}c_l+\frac{d(bn-d+dn)(2bn+dn-2ds+2dns)}{(2bn+dn-ds+dns)\left(4b^2n^2+6bdn^2-4bdn+2d^2n^2-4d^2n+2d^2\right)}\sum_{i\neq l}^{n}c_i\end{array}\right) \\ & -\frac{\left(2b^2n^2+3bdn^2-2bdn+d^2n^2-2d^2n+d^2\right)s}{\left(2bn+dn-ds+dns\right)\left(2bn+dn-2ds+2dns\right)}c_l+\frac{\left(bn-d+dn\right)\left(d+2bn+dn-2ds+dns\right)}{\left(2bn-d+2dn\right)\left(2bn+dn-ds+dns\right)}c_{i\neq l} \\ & +\frac{d\left(1-s\right)\left(bn-d+dn\right)}{\left(2bn-d+2dn\right)\left(2bn+dn-ds+dns\right)}\sum_{k\neq i\neq l}^{n}c_k, \end{aligned} \tag{30}$$

so that the parameters of interest are:

$$
\begin{aligned}
B_{l,21} &= \frac{2bn + dn}{4bn + 2dn - 2ds + 2dns} \\
B_{l,22} &= \frac{d\left(bn - d + dn\right)\left(2bn + dn - 2ds + 2dns\right)}{\left(2bn + dn - ds + dns\right)\left(4b^2n^2 + 6bdn^2 - 4bdn + 2d^2n^2 - 4d^2n + 2d^2\right)} \\
B_{i\neq l,1} &= \frac{d + \left(2bn + 2d\left(n-1\right)\right)s}{\left(2b+d\right)n + 2d\left(n-1\right)s} \\
B_{i\neq l,21} &= \frac{\left(\left(b+d\right)n - d\right)\left(\left(2b+d\right)n + d\left(n-2\right)s + d\right)}{\left(2n\left(b+d\right) - d\right)\left(\left(2b+d\right)n + d\left(n-1\right)s\right)} \\
B_{i\neq l,22} &= -\frac{\left(2b^2n^2 + 3bdn^2 - 2bdn + d^2n^2 - 2d^2n + d^2\right)s}{\left(2bn + dn - ds + dns\right)\left(2bn + dn - 2ds + 2dns\right)} \\
B_{i\neq l,23} &= \frac{d\left(n\left(b+d\right) - d\right)\left(1-s\right)}{\left(2n\left(b+d\right) - d\right)\left(\left(2b+d\right)n + d\left(n-1\right)s\right)}.
\end{aligned}
$$

A.2 Fully Coordinated PLB Equilibrium

Fully coordinated monopoly pricing by the leader is an equilibrium if $r^*_{i\neq l}\left(r_l^{PLB}\right) \leq r_l^{PLB}$, which holds for a wide range relevant values of Δc. Since bank l knows that $r_{i\neq l} = r_l$ for all followers, it determines its optimal rate simply by

$$\max_{r_l} \pi_l^{PLB} = (r_l - c_l)(a + e - br_l).$$

From

$$\frac{d\pi_l^{PLB}}{dr_l} = a + e - 2br_l + c_l b = 0$$

it follows that

$$r_l^{PLB} = \frac{a+e}{2b} + \frac{1}{2}c_l = r_{i\neq l}^{PLB} \gg \max\left(r_l^*, r_{i\neq l}^*\right) \text{ for } c < a + e, \text{ for all } i \neq l. \tag{31}$$

The condition $c < a + e$ obviously is a necessary condition for the market to exist.

B Data Sources

The raw data set of NHG-backed mortgage transactions contained 978, 704 observations and was cleaned by correcting obvious errors. Removed were all observations where the interest rate was zero or missing (15 observations), which had a negative or missing maturity (2, 903 observations), and with a maturity over 100 years (919 observations). Obvious typos were repaired (10), or removed (3) when it was not clear what was meant—for example a 10 was corrected into .10 (10%), but a 24 would be taken out if it could not be determine with certainty whether 2.4% or 24% would have been the actual observation. The clean data set consists of 974, 864 rate observations. There were only 5 cases of interest rates lower than 1%, which may also include typos. Excluding them did not change the results.

Data on base interest rates was taken from the Dutch Central Bank's online statistical data (Table 1.3.1). This data set presents the nominal interest rate term structure that is used to calculate liabilities for pension funds, which itself is based on interbank interest rates. Rates are presented at different maturities with one-year maturity intervals, and have a monthly frequency. Base rate maturities were matched with mortgage maturities.

Data on the Eonia interest rate for overnight maturity was obtained from the ECB statistical data warehouse. The rate is weighted by the ECB and calculated from data collected on unsecured overnight lending in the Euro area as provided by banks belonging to the Eonia panel. The data series has a daily frequency and is not differentiated by maturity.

Data on deposit rates was taken from the Dutch Central Bank's online statistical data (Table 5.2.7). It is the rate on deposits that are redeemable at notice with a period of notice less than three months. As banks are known to base the financing of part of their mortgage loans on deposits, this series proxies for part of the costs of attracting funding. The data on deposit rates has a monthly frequency and is not differentiated by maturity.

Data on CDS spreads (only senior debt) was obtained from Thomson Datastream, available for maturities at 1, 4, 5, 7, and 10 years for all five main mortgage providers (Rabobank, ING, ABN AMRO, AEGON and SNS). These CDS spreads were matched by maturity a much as possible—for example were mortgages with a maturity of 3 years matched with 4-year CDS spreads and mortgages with a maturity over 10 years with 10-year CDS spreads. The data series on CDS spreads has a daily frequency.

Data on the Tier1 ratio was taken from the Dutch Central Bank's online statistical data (Table 10.1). It contains the average amount of Tier1 capital over risk-weighted assets that is a proxy for the costs of equity and adhering to capital regulation (Basel II and/or III) for the Dutch banks. The data on the Tier1 ratio has a quarterly frequency and is not differentiated by maturity.

Data on the HHI was calculated from the NHG data set directly, by calculating the shares in the total number of NHG mortgages of all maturities together over the providers per month, and taking the sum of these market shares squared. Differentiation by maturity led to high outlier values (regularly exactly 1) where there were only few mortgages supplied for several mortgage types in certain months. The 10-year maturity category of mortgages did have enough observations to create a meaningful HHI series for use in the analysis of this category in isolation.

C Controlling for Cost Changes

Controlling in cointegration equation (13) for changes in costs is essential to obtain proper estimates. Figure 4 pictures the equilibrium best-response of a follower to the leader's interest rate. From equilibrium A, suppose an increase in r_l is accompanied by an increase in the costs of the follower—which is typically correlated to a cost increase for the leader, which may be the source of Δr_l. The cost increase shifts the equilibrium best-response curve upwards, so that the new equilibrium interest rate is in point B. If the relationship between r_l and $r_{i \neq l}$ were empirically measured from observations A and B without controlling for the cost change, the response would be overestimated compared to the actual value of the slope of the best-response function. The overestimation can make it impossible to distinguish between competitive and coordinated price leadership, in which the response is expected to be unity.

To see the effects of (partially) controlling for cost changes, we have estimated the cointegration equation (13) with different combinations of cost factors included for the third largest bank C.[76] We conjecture bank C to be AEGON, for which the

[76] Bank C was chosen for lack of data on the main 10-year mortgage rate category for bank B.

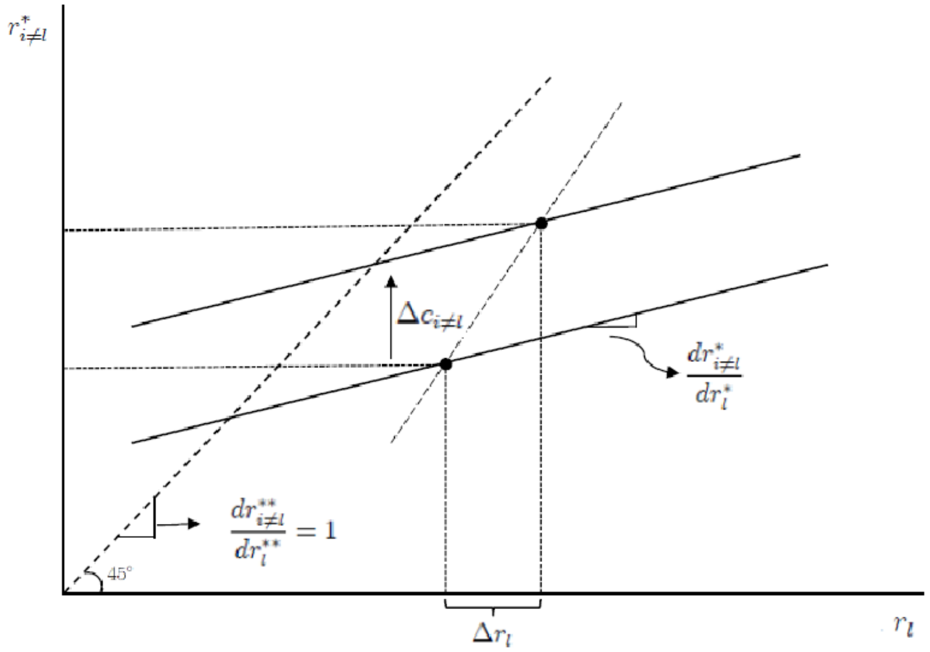

Figure 4: Follower banks equilibrium price best-responses to price leader's rate.

we find February 13, 2009 as the most likely break date. Table C.1. collects the relevant results, showing how the coefficients change when costs are partially or fully controlled for, versus not at all.

Table C.1: Results cointegrating equation for bank C with varying cost controls

	$r_{C,t}$	$r_{C,t}$	$r_{C,t}$	$r_{C,t}$	$r_{C,t}$
break date	13-02-09	13-02-09	13-02-09	13-02-09	13-02-09
$r_{A,t-1}$	.6866***	.1631***	.2598***	.0245	.0948**
	(.0088)	(.0169)	(.0191)	(.0162)	(.0480)
$r_{A,t-1} \times D_t^{PLB}$	−.0166*	.4574***	.3350***	.5043***	.4707***
	(.0099)	(.0176)	(.0202)	(.0166)	(.0512)
D_t^{PLB}	.00175***	.0180***	.0229***	.0107***	−.0001
	(.0005)	(.0004)	(.0011)	(.0011)	(.0022)
cost factors	no	deposits	all	all	all plus RMBS
maturity FE	no	no	no	yes	yes
N	59876	59767	59767	59767	25369
R^2	.4472	.5281	.5793	.6835	.5945

Notes: Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

The results in the first column are without accounting for costs. The coefficient on $r_{A,t-T}$ is overestimated in the competitive regime and not affected by the price leadership bans: the (negative) coefficient on $r_{A,t-T} \times D_t^{PLB}$ cannot be distinguished from zero and is insignificant. By only including the deposit rate, in the second column, the coefficients take on values that are in line with the results in the main text and theory. The deposit rate is relevant because on average during the 2004-2012 period about 45% of the liabilities of the Dutch banks was funded through deposits.[77] The coefficient on $r_{deposit,t}$ is close to 1 and the coefficient on $r_{deposit,t} \times D_t^{PLB}$ is close to -1, yet by a Wald test the hypothesis that they add up to zero is rejected at the 1% significance level. The results are somewhat more pronounced when including the other cost components as in the main text (fourth column). The final column shows that also including RMBS spreads and/or fixed effects does not critically alter the main findings, so that leaving it out as we do in the main text is not problematic.

D Non-stationarity

Unit roots have been tested for in the 10-year maturity, which constitutes 55.5% of all observations in our data set. Table $D.1$ presents the Dickey-Fuller test statistics for non-stationarity in the interest rate data, daily averages by provider. The table results are based on 5 autoregressive terms, selected to align the unit root tests to the VAR tests that are used to determine Granger causality in Section 7 in the main text. Similar results were obtained when the number of autoregressive terms was selected based off the Schwartz Information Criterion, which found 5 to 10 autoregressive terms, depending on the data series.

Table $D.1$: Dickey-Fuller test statistics for interest rates, 10-year maturity, daily averages

	Levels		First differences	
	t-value	probability	t-value	probability
$r_{A,t}$	$-.783$	.377	-29.989	.000
$r_{B,t}$	$-.663$	.430	-25.017	.000
$r_{C,t}$	.334	.782	-24.634	.000
$r_{D,t}$	$-.558$	.476	-31.011	.000
$r_{E,t}$	$-.824$	.359	-27.870	.000
$r_{F,t}$	$-.385$	.795	-31.931	.000
$r_{G,t}$	.856	.895	-32.534	.000
$r_{H,t}$	.240	.756	-16.597	.000

Notes: no trend or constant included.

Similar results are obtained for the other main mortgage type series, 5- and 20-year maturity. The tests show that all series display unit roots in levels, but not in first differences.

Table $D.2$ presents the Johansen trace statistic for cointegration tests on the raw data series, between pairs of daily averages of the 10-year interest rate set by bank A

[77] Source: DNB statistics, Table 5.2.

and the other banks B to H, respectively, with 5 autoregressive terms.[78]

Table $D.2$: Johansen trace tests for pairwise cointegration with $r_{A,t}$, 10-year daily averages

	no cointegrating eq.		at most one cointegrating eq.	
	trace statistic	p-value	trace statistic	p-value
$r_{B,t}$	26.451	.000	1.228	.313
$r_{C,t}$	17.567	.006	.601	.499
$r_{D,t}$	47.949	.000	1.312	.295
$r_{E,t}$	50.022	.000	.975	.375
$r_{F,t}$	16.770	.009	.153	.747
$r_{G,t}$	26.491	.000	.125	.771
$r_{H,t}$	22.478	.001	.065	.835

Notes: no trend or constant assumed, five autoregressive terms.

The hypothesis of no cointegration is rejected for each interest rate pair, and the existence of at most one cointegrating equation can not be rejected.

E Multicollinearity

Table $E.1$ presents correlations between the relevant variables. In particular does the RMBS spread correlate with r_A, which was therefore excluded from the analyses in the text, in order to avoid potential multicollinearity concerns.

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Table $E.1$: Correlations

Table $E.2$ presents variance inflation factors (VIF) for a regression that is similar to (13) in Section 9.2 but is estimated separately before and after the estimated break date to assess any variance inflation created by the interaction terms themselves. Multicollinearity concerns arise for VIF values over 10 (sometimes 5), which mostly are on the CDS spreads that strongly comove. For this reason, we do not interpret the coefficients on the CDS spreads in the text separately. Table $E.2$ also reveals that the VIF of r_A mostly stay under 5, and always under 10, so that there is no concern for multicollinearity between our main explanatory variable r_A and all other factors, validating our approach.

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Table $E.2$: Variance Inflation Factors

[78] Including cost factors as exogenous variables in the cointegration tests, gives similar results. The hypothesis of no cointegration is rejected for each follower. For most rate pairs, one cointegrating equation is found—two for some. See Appendix $I.3$ for more specific cointegration tests.

Table E.1: Correlations

	r_A	CDS_{ABN}	CDS_{AEGON}	CDS_{ING}	$CDS_{Rabobank}$	CDS_{SNS}	r_{base}	$r_{deposit}$	$Tier1$	r_{Eonia}	HHI	$RMBS$
r_A	1	×	×	×	×	×	×	×	×	×	×	×
CDS_{ABN}	.44	1	×	×	×	×	×	×	×	×	×	×
CDS_{AEGON}	.42	.82	1	×	×	×	×	×	×	×	×	×
CDS_{ING}	.29	.86	.87	1	×	×	×	×	×	×	×	×
$CDS_{Rabobank}$	.41	.87	.95	.94	1	×	×	×	×	×	×	×
CDS_{SNS}	.33	.81	.94	.89	.94	1	×	×	×	×	×	×
r_{base}	.36	−.34	−.30	−.37	−.31	−.48	1	×	×	×	×	×
$r_{deposit}$	.19	−.45	−.10	−.31	−.19	−.24	.55	1	×	×	×	×
$Tier1$	.19	.81	.61	.72	.68	.73	−.66	−.70	1	×	×	×
r_{Eonia}	−.01	−.62	−.50	−.56	−.57	−.64	.71	.72	−.86	1	×	×
HHI	.33	.79	.69	.74	.73	.77	−.51	−.44	.78	−.63	1	×
$RMBS$	.48	.37	.52	.14	.43	.51	.24	.11	.31	−.42	.28	1

Table E.2: Variance Inflation Factors

	$r_{B,j,m,t}$		$r_{C,j,m,t}$		$r_{D,j,m,t}$		$r_{E,j,m,t}$		$r_{F,j,m,t}$		$r_{G,j,m,t}$		$r_{H,j,m,t}$	
response time	3		1		3		3		5		2		5	
break date	16-06-09		13-02-09		04-03-09		03-03-09		27-05-09		01-03-09		01-03-09	
	before	after	before	after	before	after	before	after	before	after	before	after	before	after
r_A	3.93	3.89	5.76	2.08	6.36	2.91	4.73	2.79	5.02	3.73	3.78	3.26	3.21	2.35
CDS_{ABN}	56.25	11.81	24.41	5.40	33.81	4.14	28.93	4.34	29.27	6.76	41.18	3.52	29.06	8.45
CDS_{AEGON}	24.02	9.14	10.28	8.51	11.13	8.40	16.50	9.46	12.62	6.58	12.38	6.92	12.65	13.11
CDS_{ING}	61.44	18.87	45.92	8.30	68.84	10.54	58.82	9.22	50.31	14.40	60.06	8.33	42.99	20.74
$CDS_{Rabobank}$	36.11	25.31	38.30	21.37	42.13	20.32	66.21	22.15	60.60	13.99	43.95	17.30	35.15	33.86
CDS_{SNS}	9.64	10.69	22.10	10.55	24.49	11.46	41.91	11.58	24.44	10.06	18.55	7.73	13.46	15.14
r_{base}	4.77	8.91	3.98	4.22	4.45	4.86	4.49	4.14	5.45	3.78	3.26	5.83	3.59	4.10
$r_{deposit}$	2.70	4.45	8.50	10.43	8.11	6.78	7.72	8.98	4.38	6.37	6.17	6.24	3.17	8.72
$Tier1$	1.52	3.72	1.50	2.41	1.25	1.72	1.34	2.02	1.50	1.30	1.48	2.22	1.93	3.59
r_{Eonia}	3.09	4.80	4.13	2.42	3.43	2.55	3.92	2.41	3.77	2.26	3.38	3.38	2.60	4.13
HHI	2.05	1.23	2.94	2.25	3.26	1.74	3.82	1.57	2.21	2.23	2.21	1.28	1.85	1.38

F Common Cost Shocks

Due to multicollinearity in the funding cost factors, the absolute value of the cost coefficient estimates cannot be meaningfully interpreted individually. Instead, we consider predictions about the sum of cost coefficients. In this section, we make precise how this comparison relates to the theory.

The model in the text considers a single 'total' marginal cost c_i per bank, which differ as either c_l for the leader, $c_{i \neq l}$ for follower $i \neq l$ and c_k for all other followers. Suppose instead that a bank i's total marginal costs consists of several (C_i) components that add up linearly, each with weight $w_{l,i}$, so that

$$c_i = \sum_{j=1}^{C_i} w_{i,j} c_{i,j}.$$

We do not have (sufficiently precise) information about the size of these weights.[79]

First consider the price-leader-bank, which sets its rate at

$$r_l^* = B_{l,0} + B_{l,21} c_l + B_{l,22} \sum_{i \neq l}^{n-1} c_i,$$

from which we can derive hypotheses for the effect of all cost components changing by the same amount (a 'common cost shock'), that is about

$$S_l = B_{l,21} + (n-1) B_{l,22}.$$

Given that total marginal costs consists of several components, the marginal change in the mortgage rate in response to a common cost shock really is

$$S_l' = B_{l,21} \sum_{j=1}^{C_l} w_{l,j} + (n-1) B_{l,22} \sum_{j=1}^{C_{i \neq l}} w_{i \neq l, j}.$$

The regression for the leader-bank is done on all cost components, that is on model (11) in Section 9.1, in which $\mathbf{C}_{m,t}$ consists of nine cost controls: CDS spreads for the biggest five mortgage providers in the Netherlands (matched by maturity), two base rates (Eonia and the interbank swap rate with maturity matched to the mortgage), the rate on Dutch deposits, and the amount of Tier1 equity capital to risk-weighted

[79] An indication can obtained from ACM, *Concurrentie op the Hypotheekmarkt: Een Update van de Margeontwikkelingen sinds begin 2011*, April 2013, in which the funding costs for mortgages are determined by a base rate (Euribor) plus roughly (the weights fluctuate monthly) .3 each by CDS, RMBS and deposit rates, .1 by capital costs and an additional 80 basis points for fixed costs. See Dijkstra and Schinkel (2013).

assets. That is, stylized for one maturity and no lags (*i.e.*, dropping j, m and t), without the HHI, and setting $D_{i,t}^{PLB} = 0$, we regress (in competition):

$$r_A = \beta_{A,0} + \sum_{j=1}^{9} \beta_{A,j,2} c_j + \epsilon_A,$$

which can be rewritten as

$$r_A = \beta_{A,0} + \sum_{j=1}^{9} \left(\overbrace{\beta_{l,21} w_{l,j} + (n-1)\, \beta_{l,22} w_{i \neq l,j}}^{\beta_{A.j,2}} \right) c_j + \epsilon_A,$$

since of each cost factor its combined effect via all banks (the leader and all followers, including bank $i \neq l$ itself) is estimated at once, including the weights which that cost factor has in all the banks total marginal costs. In other words, the parameters $\beta_{A,j,2}$ estimates the total effect of a change in cost factor c_j through all the banks in the model.

Therefore the sum of estimated coefficients, which implicitly includes estimations of the weights, is

$$\begin{aligned} \widehat{S}_l' &= \sum_{j=1}^{9} \widehat{\beta}_{A,j,2} = \sum_{j=1}^{9} \left(\widehat{\beta}_{l,21} \widehat{w}_{l,j} + (n-1)\, \widehat{\beta}_{l,22} \widehat{w}_{i \neq l,j} \right) \\ &= \widehat{\beta}_{l,21} \sum_{j=1}^{9} \widehat{w}_{l,j} + (n-1)\, \widehat{\beta}_{l,22} \sum_{j=1}^{9} \widehat{w}_{i \neq l,j}, \end{aligned}$$

which is the proper estimation of S_l' if it is assumed that $C_l = 8$, for leader and followers the same.

Next consider the followers. From the equilibrium best-reponse

$$r_{i \neq l}^* = B_{i \neq l,0} + B_{i \neq l,1} r_l^* + B_{i \neq l,21} c_{i \neq l} + B_{i \neq l,22} c_l + B_{i \neq l,23} \sum_{k \neq i \neq l}^{n-2} c_k,$$

we can derive hypotheses for the effect of all cost components changing by the same amount (a 'common cost shock') that consists of direct and indirect equilibrium effects.

With several cost components, The direct effect in the mortgage rate in response to a common cost shock is

$$S_{i \neq l}^d = B_{i \neq l,21} + B_{i \neq l,22} + (n-2)\, B_{i \neq l,23},$$

or with several components

$$S_{i \neq l}^{d\prime} = B_{i \neq l,21} \sum_{j=1}^{C_{i \neq l}} w_{i \neq l,j} + B_{i \neq l,22} \sum_{j=1}^{C_l} w_{l,j} + (n-2)\, B_{i \neq l,23} \sum_{j=1}^{C_{k \neq i \neq l}} w_{k \neq i \neq l,j}.$$

The regressions for each follower-bank are performed on all cost components, that is on model (13) in Section 9.2, in which $\mathbf{C}_{m,t}$ consists of the same nine cost controls for all follower-banks: CDS spreads for the biggest five mortgage providers in the Netherlands (matched by maturity), two base rates (Eonia and the interbank swap rate with maturity matched to the mortgage), the rate on Dutch deposits, and the amount of Tier 1 equity capital to risk-weighted assets. That is, stylized for one maturity and no lags (*i.e.*, dropping j, m and t), without the HHI, and setting $D_{i,t}^{PLB} = 0$, we obtain the following expression for the regression in competition:

$$r_{i\neq l} = \beta_{i\neq l,0} + \beta_{i\neq l,1} r_l + \sum_{j=1}^{9} \beta_{i\neq l,j,2} c_j + \epsilon_{i\neq l},$$

which can be rewritten as

$$r_{i\neq l} = \beta_{i\neq l,0} + \beta_{i\neq l,1} r_l + \sum_{j=1}^{9} \left(\overbrace{\beta_{i\neq l,21} w_{i\neq l,j} + \beta_{i\neq l,22} w_{l,j} + (n-2)\, \beta_{i\neq l,23} w_{k\neq i\neq l,j}}^{\beta_{i\neq l,j,2}} \right) c_j + \epsilon_{i\neq l},$$

since of each cost factor its combined direct effect via all banks (the leader and all followers, including bank $i \neq l$ itself) is estimated at once, including the weights. In other words, the parameters $\beta_{i\neq l,j,2}$ estimate the total *direct* effect of a change in cost factor c_j through all the banks in the model.

Therefore the sum of estimated coefficients, which implicitly includes estimations of the weights, is

$$\begin{aligned} \widehat{S}^{d\prime}_{i\neq l} &= \sum_{j=1}^{9} \widehat{\beta}_{i\neq l,j,2} = \sum_{j=1}^{9} \left(\widehat{\beta}_{i\neq l,21} \widehat{w}_{i\neq l,j} + \widehat{\beta}_{i\neq l,22} \widehat{w}_{l,j} + (n-2)\, \widehat{\beta}_{i\neq l,23} \widehat{w}_{k\neq i\neq l,j} \right) \\ &= \widehat{\beta}_{i\neq l,21} \sum_{j=1}^{9} \widehat{w}_{i\neq l,j} + \widehat{\beta}_{i\neq l,22} \sum_{j=1}^{9} \widehat{w}_{l,j} + (n-2)\, \widehat{\beta}_{i\neq l,23} \sum_{j=1}^{9} \widehat{w}_{k\neq i\neq l,j}. \end{aligned}$$

which is the proper estimation of $S^{d\prime}_{i\neq l}$ if it is assumed that $C_i = 8$, for leader and followers the same. Note that in theory, if a bank's total marginal costs are determined by fewer than the 9 cost components (for example only its own CDS spread), this would be reflected in a zero weight w_{ij} on that cost factor. By including in the regressions more cost controls (9) than there are banks (8), we should have an outer set of determinants. Yet theoretically $\widehat{S}^{d\prime}_{i\neq l}$ would be an underestimation of $S^{d\prime}_{i\neq l}$ in case more cost factors influence to pricing decisions of some of the banks considered—for example the CDS spreads of a remote fringe.

Finally, note that since r_l is included separately in the regression (13), the *indirect* effect of the common cost shock on $r_{i\neq l}$, through its effect on r_l^* is not included in the joint cost effect. We can combine the estimated elements to make predictions about the the full common cost shock effect on a followers equilibrium rate derived in the text, which is

$$\begin{aligned} S_{i\neq l} &= S^d_{i\neq l} + B_{i\neq l,1}S_l. \\ &= B_{i\neq l,21} + B_{i\neq l,22} + (n-2)\,B_{i\neq l,23} + B_{i\neq l,1}S_l \\ &= B_{i\neq l,21} + B_{i\neq l,22} + (n-2)\,B_{i\neq l,23} + B_{i\neq l,1}\left(B_{l,21} + (n-1)\,B_{l,22}\right). \end{aligned}$$

G Baseline Estimation Results

G.1 Equilibrium Conditions

The tables below present the raw estimation results for individual observations.

Table G.1. Regression results bank A's rate to costs, individual rates

	price-leader response		Log-specification	
break date	01-03-2009 (495.3461)		01-07-2009 (404.3552)	
	before	$\times D^{PLB}_{A,t}$	before	$\times D^{PLB}_{A,t}$
CDS_{ABN}	.1564*** (.0232)	−.2601*** (.0282)	.0625*** (.0030)	−.0054 (.0063)
CDS_{AEGON}	.0190*** (.0059)	−.0055 (.0080)	−.0143*** (.0027)	.0881*** (.0042)
CDS_{ING}	.04817* (.0278)	−.1097*** (.0284)	−.0188*** (.0042)	−.0568*** (.0054)
$CDS_{Rabobank}$	−.3936*** (.0306)	.7170*** (.0348)	−.0325*** (.0031)	.0858*** (.0051)
CDS_{SNS}	−.0333*** (.0076)	−.1561*** (.0084)	.0133*** (.0014)	−.1003*** (.0039)
$r_{deposit}$	2.082*** (.0183)	−1.289*** (.0232)	.9679*** (.0109)	−.4539*** (.0139)
r_{base}	.2879*** (.0061)	.0181*** (.0061)	.2264*** (.0048)	−.0752*** (.0048)
r_{eonia}	−.1119*** (.0027)	−.0147** (.0069)	−.0820*** (.0012)	.0582*** (.0015)
$Tier1$	−.1018*** (.0041)	.1128*** (.0061)	−.2244*** (.0096)	−.0627*** (.0159)
HHI	.0311*** (.0020)	−.0216** (.0021)	.0399*** (.0038)	−.0089* (.0048)
S_l	1.8462*** (.0166)	−.9873*** (.0267)	×	×
T_A	×	×	.8980*** (.0151)	−.5222*** (.0214)
N	176442		176442	
R^2	.6262		.6536	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

Table $G.2$: Results interest best-response follower banks' to bank A's rate, cost factors, HHI and maturity fixed-effects, individual rates

	$r_{B,j,m,t}$	$r_{C,j,m,t}$	$r_{D,j,m,t}$	$r_{E,j,m,t}$	$r_{F,j,m,t}$	$r_{G,j,m,t}$	$r_{H,j,m,t}$
time to response	3 days	1 day	3 days	3 days	5 days	2 days	5 days
break date	16-06-09	13-02-09	04-03-09	03-03-09	27-05-09	01-05-09	01-05-09
	(686.990)	(581.596)	(243.678)	(310.731)	(75.591)	(153.646)	(507.252)
$r_{A,m,t-\tau}$	.095***	.024	.206***	.116***	.133***	.169***	.122***
	(.018)	(.016)	(.022)	(.010)	(.009)	(.011)	(.006)
$r_{A,m,t-\tau} \times D_{f,t}^{PLB}$	.231***	.504***	.635***	.472***	.391***	.376***	−.331***
	(.0564)	(.017)	(.023)	(.013)	(.019)	(.016)	(.030)
$CDS_{ABNAMRO}$	−.434***	.313***	.087***	.268***	−.061*	.230***	−.271**
	(.066)	(.021)	(.033)	(.027)	(.037)	(.031)	(.123)
$CDS_{ABN} \times D_{f,t}^{PLB}$	.738***	−.477***	.005	−.406***	.448***	−.417***	.628***
	(.140)	(.030)	(041)	(.035)	(.060)	(.047)	(.190)
CDS_{Aegon}	.017	.029***	−.067***	.006	−.012*	.047***	.065
	(.025)	(.005)	(.005)	(.007)	(.007)	(.008)	(.054)
$CDS_{Aegon} \times D_{f,t}^{PLB}$	−.104***	−.010	.140***	.131***	.090***	.020	.047
	(.029)	(.007)	(.009)	(.010)	(.021)	(.014)	(.061)
CDS_{ING}	.351***	−.057**	−.240***	−.287***	.179***	−.160***	−.031
	(.088)	(.024)	(.038)	(.030)	(.042)	(.033)	(.147)
$CDS_{ING} \times D_{f,t}^{PLB}$	−.630***	−.108***	.089**	−.063**	−.145***	.037	.007
	(.090)	(.026)	(.039)	(.031)	(.048)	(.037)	(.154)
$CDS_{Rabobank}$	.425***	−.483***	.220***	.143***	.075	−.021	.306
	(.097)	(.029)	(.030)	(.036)	(.047)	(.041)	(.193)
$CDS_{Rabobank} \times D_{f,t}^{PLB}$	.045	.737***	−.428***	−.024	−.554***	−.037	−.371
	(.102)	(.035)	(.038)	(.043)	(.069)	(.050)	(.208)
CDS_{SNS}	−.342***	−.120***	−.110***	−.030***	.001	−.073***	−.249***
	(.025)	(.007)	(.007)	(.006)	(.011)	(.010)	(.046)
$CDS_{SNS} \times D_{f,t}^{PLB}$	.395***	.097***	.190***	.006	.037**	.060***	.142***
	(.028)	(.008)	(.009)	(.010)	(.018)	(.012)	(.060)
$r_{deposit}$	2.311***	2.523***	1.998***	1.550***	1.309***	1.775***	1.680***
	(.056)	(.041)	(.056)	(.031)	(.027)	(.034)	(.037)
$r_{deposit} \times D_{f,t}^{PLB}$	−4.046***	−2.288***	−1.798***	−1.450***	−.644***	−1.558***	−1.360***
	(.077)	(.043)	(.057)	(.037)	(.057)	(.044)	(.113)
r_{base}	.054***	−.132***	−.065***	.146***	.161***	.006	.155***
	(.013)	(.011)	(.014)	(.009)	(.008)	(.010)	(.008)
$r_{base} \times D_{f,t}^{PLB}$	.574***	.149***	.025	−.250***	−.256***	−.087***	−.121***
	(.031)	(.013)	(.016)	(.011)	(.014)	(.014)	(.028)
r_{Eonia}	−.225***	−.110***	−.016**	−.022***	.011**	−.111***	−.107***
	(.005)	(.006)	(.006)	(.005)	(.005)	(.006)	(.004)
$r_{Eonia} \times D_{f,t}^{PLB}$	.166***	−.112***	−.034***	.037***	.001	.164***	.049
	(.034)	(.011)	(.011)	(.011)	(.016)	(.013)	(.058)
$Tier1$	−.188***	−.080***	−.154***	−.113***	−.043***	−.024***	−.111***
	(.008)	(.006)	(.008)	(.004)	(.005)	(.005)	(.010)
$Tier1 \times D_{f,t}^{PLB}$	−.131**	.161***	.310***	.233***	.183***	.125***	−.020
	(.051)	(.007)	(.010)	(.008)	(.013)	(.013)	(.070)
HHI	.092***	.039***	.057***	.036***	.050***	.005	.110***
	(.004)	(.003)	(.004)	(.003)	(.002)	(.003)	(.003)
$HHI \times D_{f,t}^{PLB}$	−.101***	.030***	−.040***	−.029***	−.021***	−.005	−.115***
	(.005)	(.006)	(.005)	(.003)	(.005)	(.003)	(.003)
$D_{f,t}^{PLB}$	.094***	.011***	−.016***	.007***	−.008***	−.005	−.115***
	(.006)	(.001)	(.001)	(.001)	(.002)	(.003)	(.003)
maturity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	56088	59767	62540	55230	57255	46485	32939
R^2	.4551	.6835	.5591	.6807	.6514	.6211	.6811

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

G.2 Cost Pass-through Elasticities

The marginal funding cost pass-through elasticities of mortgage rates resulting from estimating the full log-specification

$$\begin{aligned}\ln r_{f,j,m,t} &= \beta'_{f,m,0} + \beta^{PLB\prime}_{f,1} \ln r_{A,m,t-\tau} + \boldsymbol{\beta}'_{f,2} \ln \mathbf{C}_{m,t} \\ &\quad + \left(\beta^{PLB\prime}_{f,0} + \beta^{PLB\prime}_{f,1} \ln r_{A,m,t-\tau} + \boldsymbol{\beta}^{PLB\prime}_{f,2} \ln \mathbf{C}_{m,t}\right) D^{PLB\prime}_{f,t} + \epsilon_{f,j,m,t}, \quad (32)\end{aligned}$$

per follower are given in Table $G.3$.

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Table $G.3$: Cost pass-through elasticities, including $\ln r_{A,m,t-\tau}$ for price-follower banks, individual rates

H Realized Best-responses

Table $H.1$ summarizes the three main findings on follower behavior of all banks, for direct comparison to the predictions in Table 8.1 in the main text.

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Table $H.1$: Realized best-response results follower-banks' to bank A's rate and costs, individual rates

I 10-year Maturity Estimation Results

I.1 Equilibrium Conditions

The tables below presents the raw equilibrium best-responses estimation results for 10-year daily averages, for price-leader Bank A and the followers.

Table G.3: Cost pass-through elasticities, including lnrA for price-follower banks, individual rates

	$r_{B,j,m,t}$		$r_{C,j,m,t}$		$r_{D,j,m,t}$		$r_{E,j,m,t}$	
break date	16-06-09		18-11-08		05-03-09		03-03-09	
	(594.078)		(573.416)		(187.742)		(277.839)	
	before	$\times D^{PLB}_{B,t}$	before	$\times D^{PLB}_{C,t}$	before	$\times D^{PLB}_{D,t}$	before	$\times D^{PLB}_{E,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	$.701^{***}$	-2.006^{***}	$.996^{***}$	$-.816^{***}$	$.876^{***}$	$-.394^{***}$	$.722^{***}$	$-.517^{***}$
	(.041)	(.122)	(.022)	(.026)	(.039)	(.044)	(.019)	(.028)
N	56088		59767		62540		57255	
R^2	.484		.714		.569		.681	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

	$r_{F,j,m,t}$		$r_{G,j,m,t}$		$r_{H,j,m,t}$	
break date	29-04-09		2-12-08		29-01-08	
	(88.846)		(200.870)		(614.562)	
	before	$\times D^{PLB}_{F,t}$	before	$\times D^{PLB}_{G,t}$	before	$\times D^{PLB}_{H,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	$.809^{***}$	$-.093^{**}$	$.832^{***}$	$-.555^{***}$	$.789^{***}$	$-.590^{***}$
	(.022)	(.047)	(.016)	(.037)	(.026)	(.103)
N	57255		46485		32939	
R^2	.681		.648		.715	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

Table H.1: Realized best-response results follower-banks' to bank A's rate and costs, individual rates

	$r_{B,j,m,t}$			$r_{C,j,m,t}$			$r_{D,j,m,t}$			$r_{E,j,m,t}$		
	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)
$B_{f,1}$	.095	.326	243	.024	.528	2100	.206	.841	308	.116	.588	407
S_f^d	1.970	−1.024	−152	1.883	.031	−98	1.654	.150	−91	1.663	−.114	−107
S_f	2.145	−.744	−134	1.927	.485	−74	2.034	.872	−57	1.88	.40	−79
T_f	.969	−.626	−165	.959	.318	−67	1.156	.737	−36	.883	.345	−61
T_f'	.701	−1.305	−286	.996	.180	−82	.876	.482	−45	.722	.205	−72

	$r_{F,j,m,t}$			$r_{G,j,m,t}$			$r_{H,j,m,t}$		
	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)	before	after	$\frac{\text{after}-\text{before}}{\text{before}}$ (%)
$B_{f,1}$	.133	.524	294	.169	.545	222	.122	−.209	−271
S_f^d	1.620	.776	−52	1.688	−.005	−100	1.437	.439	−69
S_f	1.866	1.226	−34	2.000	.463	−77	1.662	.259	−84
T_f	.912	.89	−2	.911	.569	−38	.862	−.503	−158
T_f'	.809	.716	−11	.832	.277	67	.789	.199	−75

Table $I.1$. Regression results bank A's rate to costs, 10-year daily averages

	price-leader response		log-specification	
break date	28-02-2009 (312.4729)		25-11-2009 (404.3552)	
	before	$\times D^{PLB}_{A,t}$	before	$\times D^{PLB}_{A,t}$
CDS_{ABN}	.2550***	.0038	.0217***	.0544***
	(.0596)	(.0770)	(.0099)	(.0132)
CDS_{AEGON}	−.0262***	.0455***	.0046	.0471***
	(.0094)	(.0163)	(.0061)	(.0081)
CDS_{ING}	−.1872***	.0616	.0384***	−.0553***
	(.0703)	(.0726)	(.0125)	(.0138)
$CDS_{Rabobank}$	−.2922***	.2638***	−.0681***	.0300**
	(.0634)	(.0785)	(.0084)	(.0122)
CDS_{SNS}	−.0119	−.2451***	−.0175***	−.1799***
	(.0164)	(.0200)	(.0041)	(.0078)
$r_{deposit}$	2.5076***	−1.3094***	1.3599***	−.7460***
	(.0502)	(.0744)	(.0285)	(.0358)
r_{base}	.1945***	−.1963***	.1675***	−.1611***
	(.0153)	(.0214)	(.0139)	(.0163)
r_{eonia}	−.0761***	−.0270	−.0673***	.0499***
	(.0072)	(.0222)	(.0048)	(.0052)
$Tier1$	−.1478***	.1030***	−.2721***	.0916**
	(.0117)	(.0173)	(.0274)	(.0377)
HHI	−.0005	−.0223**	.0319***	−.1023***
	(.0026)	(.0030)	(.0109)	(.0123)
$Cons$	−.0109***	.0495***	1.4395***	−3.1215***
	(.0014)	(.0025)	(.1156)	(.1453)
S_l	2.216***	−.9873***	×	×
	(.0404)	(.0267)		
T_A	×	×	1.1673***	−.8695***
			(.0437)	(.0532)
N	2253		2253	
R^2	.9091		.9149	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

Table I.2: Results interest best-response follower banks' to bank A's rate, 10-year daily averages

	$r_{B,j,m,t}$	$r_{C,j,m,t}$	$r_{D,j,m,t}$	$r_{E,j,m,t}$	$r_{F,j,m,t}$	$r_{G,j,m,t}$	$r_{H,j,m,t}$
time to response	3 days	1 day	3 days	3 days	5 days	2 days	5 days
break date	13-01-09	26-01-09	04-03-09	24-02-09	27-05-09	06-01-09	14-01-08
	(31.514)	(27.858)	(61.707)	(72.984)	(70.824)	(17.182)	(18.439)
$r_{A,m,t-\tau}$	.3854***	.3855***	.4220***	.2452***	.2382***	.2776***	.2596***
	(.0445)	(.0604)	(.0414)	(.0377)	(.0282)	(.0611)	(.0329)
$r_{A,m,t-\tau} \times D^{PLB}_{f,t}$	.1868**	.4178***	.5846***	.6291***	.6333***	.5290***	−.2242
	(.1099)	(.0690)	(.0577)	(.0582)	(.0593)	(.0742)	(.1441)
$CDS_{ABNAMRO}$	−.2553*	.1086	−.1181*	.0284	−.02103***	.4765***	−.7232***
	(.1324)	(.0926)	(.0685)	(.0599)	(.0657)	(.0892)	(.2550)
$CDS_{ABNAMRO} \times D^{PLB}_{f,t}$	−.0382	−.0189	.3683***	.1857**	.8645***	−.3452***	.9080***
	(.2296)	(.0176)	(.0862)	(.0887)	(.1111)	(.01127)	(.3064)
CDS_{Aegon}	.0620	.0043	−.1395***	−.0292***	−.0601***	.0513***	.3176**
	(.0398)	(.0138)	(.0119)	(.0107)	(.0128)	(.0138)	(.1457)
$CDS_{Aegon} \times D^{PLB}_{f,t}$	−.1129**	−.0189	.1409***	.1021***	.0788**	−.0794***	−.1645
	(.0572)	(.0176)	(.0226)	(.0197)	(.0345)	(.0261)	(.1591)
CDS_{ING}	.2699**	−.1456**	−.0527	−.0839	.2520***	−.3841***	−.4781
	(.1337)	(.1018)	(.0873)	(.0704)	(.0678)	(.1007)	(.3670)
$CDS_{ING} \times D^{PLB}_{f,t}$	−.4978***	−.0655	−.1365	−.2072***	−.3595***	.2673***	.4356
	(.1424)	(.1031)	(.0904)	(.0745)	(.0791)	(.1038)	(.3806)
$CDS_{Rabobank}$	−.1539	−.0435	.4169***	.2845***	.3276***	−.2454**	1.0060**
	(.2211)	(.1050)	(.0753)	(.0790)	(.0850)	(.0968)	(.5026)
$CDS_{Rabobank} \times D^{PLB}_{f,t}$	.2331	.1091	−.6735***	−.4494***	−.6730***	.2378**	−1.3597**
	(.2522)	(.1163)	(.0952)	(.1029)	(.1229)	(.1191)	(.5673)
CDS_{SNS}	−.1746***	−.0425	−.1060***	−.0965***	−.0176	−.0692***	−.8724***
	(.0529)	(.0261)	(.0166)	(.0151)	(.0189)	(.0224)	(.1533)
$CDS_{SNS} \times D^{PLB}_{f,t}$	.3262***	.0761**	.2577***	.1851***	.2470***	.1396***	.8354***
	(.0629)	(.0302)	(.0247)	(.0251)	(.0337)	(.0294)	(.1638)
$r_{deposit}$	1.5752***	1.5029***	1.7098***	1.3954***	1.2052***	2.1939***	2.0980***
	(.1521)	(.1877)	(.1267)	(.1078)	(.0904)	(.1966)	(.1185)
$r_{deposit} \times D^{PLB}_{f,t}$	−1.9607***	−1.5960***	−1.7646***	−1.5151***	−1.2245***	−2.1800***	−1.5919***
	(.2181)	(.1985)	(.1425)	(.1311)	(.1362)	(.2114)	(.3043)
r_{base}	.0761***	−.0018	−.0346*	.0109	.0577***	−.1086***	.1008***
	(.0236)	(.0369)	(.0198)	(.0234)	(.0166)	(.0352)	(.0213)
$r_{base} \times D^{PLB}_{f,t}$	.0008	−.1697***	−.0822***	−.0986***	−.1642***	.0964**	−.1452*
	(.0636)	(.0393)	(.0242)	(.0279)	(.0257)	(.0380)	(.0812)
r_{eonia}	−.1439***	−.0340**	−.0179	.0038	.0516***	−.1163***	−.1228***
	(.0161)	(.0141)	(.0109)	(.0101)	(.0096)	(.0163)	(.0160)
$r_{eonia} \times D^{PLB}_{f,t}$	.3258***	−.0201	.0453*	.0390	−.0195	.1292***	.1065
	(.0636)	(.0231)	(.0244)	(.0265)	(.0311)	(.0301)	(.0737)
$Tier1$	−.1461***	−.0531**	−.1399***	−.1404***	−.0324***	−.0407**	−.0984***
	(.0161)	(.0227)	(.0154)	(.0129)	(.0108)	(.0187)	(.0232)
$Tier1 \times D^{PLB}_{f,t}$	.1081**	.0612**	.2761***	.2559***	.2076***	.1400***	.1901***
	(.0530)	(.0251)	(.0208)	(.0190)	(.0231)	(.0259)	(.0718)
HHI	.0179***	−.0090**	.0148***	.0302***	.0064***	−.0093***	.0380***
	(.0035)	(.0043)	(.0030)	(.0029)	(.0020)	(.0032)	(.0040)
$HHI \times D^{PLB}_{f,t}$	−.0375***	−.0240***	−.0330***	−.0528***	−.0252***	−.0056	−.0420***
	(.0056)	(.0046)	(.0035)	(.0036)	(.0034)	(.0038)	(.0077)
$Constant$	.0005	−.0035	−.0039**	.0063***	−.0007	.0110***	−.0172***
	(.0016)	(.0024)	(.0016)	(.0016)	(.0011)	(.0023)	(.0031)
$D^{PLB}_{f,t}$	−.0375***	.0284***	−.0062*	−.0046	−.0163***	.0117***	.0408***
	(.0086)	(.0033)	(.0034)	(.035)	(.0044)	(.0042)	(.0129)
N	1657	1957	2205	2162	2217	2125	1626
R^2	.8020	.8157	.8723	.8763	.8742	.7448	.5003

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

I.2 Cost Pass-through Elasticities

The pattern of changes in the cost pass-through elasticities for the follower-banks, estimated similarly as in equation (32), is even more pronounced for 10-year maturity, without (Table $I.3$) and with (Table $I.4$) including $\ln r_{A,t-\tau}$ in specification (14) in the main text.

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Table $I.3$: Standard cost pass-through elasticities for price-follower banks, 10-year daily averages

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Table $I.4$: Cost pass-through elasticities, including $\ln r_{A,t-\tau}$ for price-follower banks, 10-year daily averages

I.3 Cointegration

The 10-year maturity daily average rates time series has unit roots and cointegration, as established in Appendix D. With the estimation results presented in Appendix $I.1$, we can refine the analysis of cointegration, using standard tests on the residuals.

Table $I.4$ shows the results for Engle-Granger two-step cointegration test, a second test for cointegration. Pairwise OLS regressions are first done between daily average 10-year mortgage rate pairs of bank A and banks B to H respectively, after which their residuals are tested for stationarity, which implies cointegration. The table shows Dickey-Fuller test statistics, together with McKinnon (2010) critical values.

Table $I.4$: Engle-Granger tests for pairwise cointegration with $r_{A,t}$, 10-year daily averages

	no cost controls		cost controls†	
	t-value	Critical value‡ (5%)	t-value	Critical value (5%)
$r_{B,t}$	−5.08	−1.939	−7.059	−5.907
$r_{C,t}$	−3.55	−1.939	−6.093	−5.907
$r_{D,t}$	−6.69	−1.939	−8.175	−5.907
$r_{E,t}$	−7.02	−1.939	−8.618	−5.907
$r_{F,t}$	−4.02	−1.939	−9.186	−5.907
$r_{G,t}$	−5.00	−1.939	−7.154	−5.907
$r_{H,t}$	−3.81	−1.939	−5.953	−5.907

Notes: No trend or constant assumed; 5 autoregressive terms.
† 10-year CDS spreads for the largest 5 banks, 10-year inter-bank swap rate, deposit rate, Eonia, Tier1 ratio and HHI.
‡ Critical values from MacKinnon (2010).

Both with and without cost controls, unit roots in the residuals are rejected, and the residuals are found to be stationary, for each interest rate pair. The Engle-Granger

Table I.3: Standard cost pass-through elasticities for price-follower banks, 10-year daily averages

	$r_{B,j,m,t}$		$r_{C,j,m,t}$		$r_{D,j,m,t}$		$r_{E,j,m,t}$	
break date	1-08-08		20-01-09		04-03-09		28-02-09	
	(140.807)		(131.109)		(181.988)		(173.004)	
	before	$\times D^{PLB}_{B,t}$	before	$\times D^{PLB}_{C,t}$	before	$\times D^{PLB}_{D,t}$	before	$\times D^{PLB}_{E,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	1.289***	−1.172***	1.090***	−1.095***	1.080***	−.639***	.783***	−.460***
	(.054)	(.123)	(.068)	(.080)	(.051)	(.071)	(.042)	(.066)
N	1674		1977		2229		2186	
R^2	.800		.802		.837		.852	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

	$r_{F,j,m,t}$		$r_{G,j,m,t}$		$r_{H,j,m,t}$	
break date	30-05-09		2-12-08		12-04-08	
	(148.740)		(98.523)		(41.357)	
	before	$\times D^{PLB}_{F,t}$	before	$\times D^{PLB}_{G,t}$	before	$\times D^{PLB}_{H,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	1.012***	−.291***	1.202***	−.854***	1.431***	−1.084***
	(.038)	(.084)	(.071)	(.085)	(.080)	(.266)
N	2239		2149		1642	
R^2	.858		.761		.545	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

Table I.4: Cost pass-through elasticities, including lnrA for price-follower banks, 10-year daily averages

	$r_{B,j,m,t}$		$r_{C,j,m,t}$		$r_{D,j,m,t}$		$r_{E,j,m,t}$	
break date	06-06-08 (44.023)		02-03-09 (27.156)		02-03-09 (60.807)		24-02-09 (84.402)	
	before	$\times D^{PLB}_{B,t}$	before	$\times D^{PLB}_{C,t}$	before	$\times D^{PLB}_{D,t}$	before	$\times D^{PLB}_{E,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	$.802^{***}$	$-.861^{***}$	$.635^{***}$	$-.773^{***}$	$.587^{***}$	$-.296^{***}$	$.460^{***}$	$-.265^{***}$
	(.070)	(.134)	(.097)	(.102)	(.063)	(.074)	(.054)	(.066)
N	1657		1957		2205		2162	
R^2	.8181		.8242		.8714		.8758	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

	$r_{F,j,m,t}$		$r_{G,j,m,t}$		$r_{H,j,m,t}$	
break date	25-05-09 (94.046)		2-12-08 (27.164)		29-01-08 (20.965)	
	before	$\times D^{PLB}_{F,t}$	before	$\times D^{PLB}_{G,t}$	before	$\times D^{PLB}_{H,t}$
$\ln \mathbf{C}_{m,t}$ (T_f)	$.708^{***}$	$-.129^{***}$	$.874^{***}$	$-.706^{***}$	1.048^{***}	$-.690^{***}$
	(.046)	(.081)	(.096)	(.107)	(.100)	(.247)
N	2217		2125		1626	
R^2	.8761		.7765		.5492	

Notes: Break date with F-statistic. Robust standard errors in parentheses; *,**,*** indicating significance at the 10, 5 and 1% level respectively.

tests therefore also point at cointegration between the pairwise 10-year daily average mortgage rates.

These findings support our interpretation of the results from the regressions in levels in Appendix $I.1$, which are cointegration equations, as long-run equilibrium best-response functions between the banks' interest rates.

I.4 Response Adjustment in 10-year Maturity

The 10-year maturity daily average rates time series displaying cointegration implies that estimations of the first differences can be interpreted as short-run deviations from the long-run best-response functions between a follower's and the leader's rate. Table $I.5$ presents the full results of the short-run adjustment equation (15) for the daily average 10-year mortgage rates, given the estimated long-run equilibrium break dates.

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Table $I.5$: Response adjustment results follower banks' rate to bank A's rate and costs, 10-year daily averages

J Response Adjustment in the Full Sample

Analoguous to estimating response adjustments in the 10-year maturity, we can regress for each mortgage observation the first difference between its rate and the average mortgage rate for that maturity from one week before ($\tau = 5$). Let these differences be $r_{f,j,m,t} - \bar{r}_{f,j,m,t-5}$ for the leader and $r_{A,m,t-\tau} - \bar{r}_{A,m,t-\tau-5}$ for the follower. We estimate

$$\begin{aligned} r_{f,j,m,t} - \bar{r}_{f,j,m,t-5} &= \gamma_{f,m,0} + \gamma_{f,1}\left(r_{A,m,t-\tau} - \bar{r}_{A,m,t-\tau-5}\right) + \boldsymbol{\gamma}_{f,2}\left(\mathbf{C}_{m,t} - \bar{\mathbf{C}}_{m,t-5}\right) \\ &\quad + \left[\gamma_{f,0}^{PLB} + \gamma_{f,1}^{PLB}\left(r_{A,m,t-\tau} - \bar{r}_{A,m,t-\tau}\right) + \boldsymbol{\gamma}_{f,2}^{PLB}\left(\mathbf{C}_{m,t} - \bar{\mathbf{C}}_{m,t-5}\right)\right] \\ &\quad \times D_{f,t}^{PLB} + \theta_f \bar{\epsilon}_{f,m,t-5} + \varepsilon_{f,j,m,t}, \end{aligned} \tag{33}$$

in which the weekly first differences in costs $\mathbf{C}_{m,t} - \bar{\mathbf{C}}_{m,t-5}$ are controls, and $\bar{\epsilon}_{f,m,t-5}$ is the weekly average residual from the baseline estimation results from equation (13), which we here interpret as a cointegration equation. Maturity fixed effects are captured in $\gamma_{f,m,0}$. The dummies $D_{f,t}^{PLB}$ are timed according to the long-run equilibrium baseline break dates.

Table $I.5$: Response adjustment results follower banks' rate to bank A's rate and costs, 10-year daily averages

	$r_{B,j,m,t}$	$r_{C,j,m,t}$	$r_{D,j,m,t}$	$r_{E,j,m,t}$	$r_{F,j,m,t}$	$r_{G,j,m,t}$	$r_{H,j,m,t}$
time to response	3 days	1 day	3 days	3 days	5 days	2 days	5 days
break date	13-01-09	26-01-09	04-03-09	24-02-09	27-05-09	06-01-09	14-01-08
$\Delta r_{A,m,t-\tau}$	.146***	.273***	.180***	.131***	.133***	.137*	.124***
	(.037)	(.065)	(.035)	(.029)	(.028)	(.073)	(.039)
$\Delta r_{A,m,t-\tau} \times D^{PLB}_{f,t}$	.114	.064	.287***	.302***	.423***	.168	−.436
	(.078)	(.080)	(.066)	(.063)	(.087)	(.110)	(.226)
ϵ_{t-5}	−.790***	−.870***	−.753***	−.699***	−.819***	−.899***	−.922***
	(.038)	(.033)	(.029)	(.034)	(.033)	(.032)	(.071)
$\Delta CDS_{ABNAMRO}$	.111	.119	−.055	−.105*	−.258**	.369***	.147
	(.128)	(.104)	(.078)	(.056)	(.102)	(.096)	(.361)
$\Delta CDS_{ABNAMRO} \times D^{PLB}_{f,t}$	.315	.027	.136	.187**	.544***	−.425***	.655
	(.493)	(.115)	(.107)	(.082)	(.184)	(.141)	(.472)
ΔCDS_{Aegon}	.133***	−.013	−.069***	−.029	−.037*	.049***	.290
	(.046)	(.016)	(.014)	(.019)	(.022)	(.015)	(.204)
$\Delta CDS_{Aegon} \times D^{PLB}_{f,t}$	−.186**	.002	.084*	.047*	−.013	−.081	−.152
	(.073)	(.022)	(.047)	(.026)	(.058)	(.051)	(.248)
ΔCDS_{ING}	.066	−.144	.153*	.098	.237**	−.402***	−.539
	(.166)	(.121)	(.091)	(.059)	(.097)	(.123)	(.463)
$\Delta CDS_{ING} \times D^{PLB}_{f,t}$	−.247	.060	−.238**	−.170**	−.185	.294**	.417
	(.179)	(.126)	(.100)	(.071)	(.122)	(.136)	(.541)
$\Delta CDS_{Rabobank}$	−.567***	−.016	−.000	.110	.292***	.011	.357
	(.170)	(.138)	(.074)	(.075)	(.102)	(.101)	(.574)
$\Delta CDS_{Rabobank} \times D^{PLB}_{f,t}$	.793***	−.045	−.110	−.128	−.514***	.170	−.704
	(.216)	(.149)	(.101)	(.097)	(.180)	(.159)	(.759)
ΔCDS_{SNS}	−.118**	.010	−.029	−.029	.062**	.044	−.580*
	(.058)	(.037)	(.030)	(.024)	(.025)	(.031)	(.302)
$\Delta CDS_{SNS} \times D^{PLB}_{f,t}$	.183***	.025	.084*	.053	.039	.027	.531
	(.065)	(.041)	(.047)	(.035)	(.049)	(.056)	(.339)
$\Delta r_{deposit}$	.755*	.659	.576**	.583***	.494*	.696***	1.173***
	(.447)	(.451)	(.265)	(.185)	(.259)	(.237)	(.167)
$\Delta r_{deposit} \times D^{PLB}_{f,t}$	−1.306**	−.663	−.549*	−.522**	−.514***	−1.164***	.115
	(.562)	(.462)	(.305)	(.259)	(.180)	(.343)	(.764)
Δr_{base}	−.007	−.028	−.029	−.165***	−.066	.073	.078**
	(.076)	(.086)	(.050)	(.048)	(.054)	(.077)	(.033)
$\Delta r_{base} \times D^{PLB}_{f,t}$	.042	−.075	−.096	.071	−.103	−.057	−.269
	(.189)	(.093)	(.064)	(.060)	(.082)	(.087)	(.319)
Δr_{eonia}	−.048	−.036	.015	−.011	.013	.011	−.072**
	(.039)	(.049)	(.030)	(.024)	(.027)	(.043)	(.029)
$\Delta r_{eonia} \times D^{PLB}_{f,t}$	.084	−.006	.003	.031	.024	−.008	.071
	(.093)	(.053)	(.036)	(.033)	(.037)	(.050)	(.136)
$\Delta Tier1$	−.059**	−.030	−.120***	−.057***	−.042*	.028	−.052*
	(.028)	(.033)	(.035)	(.020)	(.023)	(.027)	(.031)
$\Delta Tier1 \times D^{PLB}_{f,t}$	.114	.016	.187***	.094***	−.017	−.018	.384**
	(.124)	(.039)	(.043)	(.034)	(.059)	(.086)	(.172)
ΔHHI	.014***	.007	−.001	.017***	.006*	.001	.026**
	(.004)	(.007)	(.004)	(.005)	(.003)	(.005)	(.004)
$\Delta HHI \times D^{PLB}_{f,t}$	−.018***	−.018**	−.004	−.023***	−.008	−.011*	−.026***
	(.006)	(.007)	(.004)	(.006)	(.005)	(.006)	(.008)
$Constant$	.000	.000	.000	−.000	−.000	.000	−.000
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
$D^{PLB}_{f,t}$	−.000	−.000	−.000	.000	.000	−.000	−.000
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
N	1472	1957	2125	2056	2168	1980	1335
R^2	.399	.452	.392	.359	.415	.360	.458

The approach is non-standard in that the cross-section of households differs over time, so that each mortgage is compared to the average of a different set of mortgages in the week before, and as such not strictly cointegration in panel data. However, household characteristics may not play a large role in interest rate setting in this sample, since in the NHG-backed mortgages providers are fully insured against default risk, so that the comparison to the average mortgage rate in the previous business week has meaning.

The relevant results of regression (33) are in Table $J.1$.

PLACE TABLE HERE

Table $J.1$: Response adjustment results follower-banks' rate to bank A's rate and costs, individual rates

The complete raw estimation results are given in Table $J.2$.

K But-for Estimations

Table $K.1$ details the but-for mortgages rates estimations per follower-bank behind the averages Table 10.1 in the main text.

PLACE TABLE HERE

Table $K.1$: Predictions of but-for mortgage rates per bank

References

[1] MacKinnon, J.G. (2010), "Critical Values for Cointegration Tests," Queen's Economics Department Working Paper, No. 1277, Queens University Kingston Ontario.

Table J.1: Response adjustment results follower-banks' rate to bank A's rate and costs, individual rates

	$\Delta r_{B,j,m,t}$	$\Delta r_{C,j,m,t}$	$\Delta r_{D,j,m,t}$	$\Delta r_{E,j,m,t}$	$\Delta r_{F,j,m,t}$	$\Delta r_{G,j,m,t}$	$\Delta r_{H,j,m,t}$
response time	3	1	3	3	5	2	5
break date	16-06-09	13-02-09	04-03-09	03-03-09	27-05-09	01-05-09	01-05-09
$\Delta r_{A,j,m,t-\tau}$	.049***	.015	.064***	.047***	.029***	.057***	.028***
	(.019)	(.011)	(.027)	(.010)	(.009)	(.010)	(.005)
$\Delta r_{A,j,m,t-\tau} \times D^{PLB}_{f,t}$	.031	.082***	.201***	.097***	.146***	.088***	−.047
	(.030)	(.013)	(.033)	(.020)	(.037)	(.025)	(.076)
$\epsilon_{f,j,m,t-5}$	−.632***	−.434***	−.674***	−.612***	−.695***	−.743***	−.578***
	(.019)	(.019)	(.018)	(.012)	(.012)	(.013)	(.023)
$\Delta \mathbf{C}_{m,t}$ (combined)	.918***	.498***	.502***	.487***	.441***	.550***	.419**
	(.199)	().094	(.131)	(.098)	(.067)	(.111)	(.178)
$\Delta \mathbf{C}_{m,t} \times D^{PLB}_{f,t}$	.190	−.510***	−.870***	−.779***	−.437***	−1.061***	−.358
	(.750)	(.107)	(.160)	(.129)	(.087)	(.187)	(1.269)
other controls	ΔHHI	ΔHHI	ΔHHI	ΔHHI	ΔHHI	ΔHHI	ΔHHI
maturity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	47035	48810	52366	45028	59785	37921	27797
R^2	.143	.105	.148	.132	.099	.190	.112

Notes: Robust standard errors in parentheses; *,** ,*** indicating significance at the 10, 5 and 1% level respectively.

Table K.1: Predictions of but-for mortgage rates per bank

	bank A			bank B			bank C			bank D		
	but-for	overcharge		but-for	overcharge		but-for	overcharge		but-for	overcharge	
		bp.	%		bp.	%		bp.	%		bp.	%
var	2.85	79.93	19.69	4.03	73.10	14.85	4.44	−5.26	−3.04	2.55	85.76	25.22
1-5	2.86	87.68	23.22	3.13	189.91	35.58	4.54	−3.07	−2.10	3.37	53.34	12.91
5	2.93	124.06	29.44	3.65	11.31	2.60	4.29	40.83	8.39	2.96	111.10	27.21
5-10	3.30	114.49	25.46	3.13	107.93	25.07	3.65	125.51	25.49	3.02	143.02	31.18
10	3.42	136.43	28.41	3.61	99.29	21.32	3.54	136.12	27.71	3.05	165.78	42.02
>10	3.65	142.70	27.64	3.44	121.73	25.25	3.63	162.14	30.90	3.16	183.37	36.34
all	3.44	136.25	28.17	3.63	81.59	17.46	3.60	144.44	28.49	3.06	161.93	34.32

Notes: Overcharges are expressed as percentage of actual rate.

	bank E			bank F			bank G			bank H		
	but-for	overcharge		but-for	overcharge		but-for	overcharge		but-for	overcharge	
		bp.	%		bp.	%		bp.	%		bp.	%
var	1.71	149.98	46.93	2.21	104.88	32.39	2.33	157.35	41.35	2.73	179.93	39.66
1-5	2.19	112.98	33.75	2.52	134.30	32.60	3.17	86.75	20.52	2.67	175.74	39.50
5	3.01	122.94	28.96	3.07	108.73	24.61	3.09	96.38	23.59	2.19	183.23	45.18
5-10	3.60	101.17	21.94	3.56	100.16	21.19	3.51	102.14	22.10	3.02	151.60	31.64
10	3.44	127.88	26.95	3.69	108.23	21.94	3.69	113.52	23.38	2.71	176.86	39.39
>10	3.72	128.05	25.16	4.11	108.61	19.87	3.90	122.32	23.23	2.87	100.69	22.04
all	3.42	127.19	26.99	3.54	108.41	22.62	3.64	112.60	23.37	2.70	174.49	38.98

Notes: Overcharges are expressed as percentage of actual rate.

Table $J.2$: Results response adjustment price-follower banks' rate to bank A's rate changes, cost factors, HHI and maturity fixed-effects, individual rates

	$\Delta r_{B,j,m,t}$	$\Delta r_{C,j,m,t}$	$\Delta r_{D,j,m,t}$	$\Delta r_{E,j,m,t}$	$\Delta r_{F,j,m,t}$	$\Delta r_{G,j,m,t}$	$\Delta r_{H,j,m,t}$
time to response	3 days	1 day	3 days	3 days	5 days	2 days	5 days
break date	16-06-09	13-02-09	04-03-09	03-03-09	27-05-09	01-05-09	01-05-09
$\Delta r_{A,m,t-\tau}$	.0485***	.0152	.0637**	.0469***	.0292***	.0565***	.0278***
	(.0185)	(.0114)	(.0269)	(.0102)	(.0093)	(.0096)	(.0054)
$\Delta r_{A,m,t-\tau} \times D^{PLB}_{f,t}$	.0310	.0823***	.2005***	.0966***	.1458***	.0879***	−.0470
	(.0295)	(.0130)	(.0326)	(.0196)	(.0366)	(.0248)	(.0764)
$\varepsilon_{f,j,m,t-5}$	−.6321***	−.4340***	−.6736***	−.6117***	−.6946***	−.7430***	−.5782***
	(.0185)	(.0192)	(.0177)	(.0120)	(.0124)	(.0130)	(.0229)
$\Delta CDS_{ABNAMRO}$	−.0853	.0391*	−.0475	.0406	−.0396	.0477	−.0500
	(.0674)	(.0204)	(.0358)	(.0291)	(.0407)	(.0310)	(.1409)
$\Delta CDS_{ABN} \times D^{PLB}_{f,t}$	1.4864**	.0481*	.0962*	−.0484	.1143	.0461	1.0177
	(.7232)	(.0266)	(.0559)	(.0400)	(.0964)	(.1081)	(1.2747)
ΔCDS_{Aegon}	−.1005***	−.0025	−.0244***	−.0065	−.0095	.0111	.0590
	(.0269)	(.0059)	(.0046)	(.0060)	(.0067)	(.0076)	(.0405)
$\Delta CDS_{Aegon} \times D^{PLB}_{f,t}$	.1493***	−.0047	.0273***	.0166*	.0185	−.0213*	−.0920**
	(.0291)	(.0073)	(.0085)	(.0086)	(.0204)	(.0122)	(.0455)
ΔCDS_{ING}	.3175***	−.0763**	.1102**	−.0188	.1210**	−.0146	−.0896
	(.0940)	(.0282)	(.0437)	(.0317)	(.474)	(.0398)	(.1646)
$\Delta CDS_{ING} \times D^{PLB}_{f,t}$	−.3923***	.0730***	−.1053**	.0181	−.1456***	.0109	.2207
	(.0957)	(.0284)	(.0175)	(.0322)	(.0509)	(.0418)	(.1681)
$\Delta CDS_{Rabobank}$	−.0069	−.0326*	−.0548***	−.0158	−.0537***	.0027	.1277
	(.0329)	(.0172)	(.0175)	(.0154)	(.0189)	(.0158)	(.0844)
$\Delta CDS_{Rabobank} \times D^{PLB}_{f,t}$	.1746***	.0195	.0002	−.0177	.0340	−.0289	−.2865***
	(.0397)	(.0191)	(.0219)	(.0206)	(.0344)	(.0248)	(.1045)
ΔCDS_{SNS}	−.0775**	.0165***	.0159***	.0080	−.0054	−.0116	−.0614
	(.0340)	(.0055)	(.0060)	(.0061)	(.0082)	(.0091)	(.0420)
$\Delta CDS_{SNS} \times D^{PLB}_{f,t}$	.1232***	−.0079	.0021	.0003	.0217	.0213*	.0623
	(.0347)	(.0066)	(.0079)	(.0077)	(.0159)	(.0122)	(.0471)
$\Delta r_{deposit}$	1.0137***	.6263***	.6429***	.5791***	.3017***	.5479***	.4573***
	(.1900)	(.0892)	(.1209)	(.0870)	(.1086)	(.1079)	(.1219)
$\Delta r_{deposit} \times D^{PLB}_{f,t}$	−1.9286***	−.6789***	−.8546***	−.7184***	.1207	−.9720***	−.2152
	(.2221)	(.0995)	(.1431)	(.1124)	(.1942)	(.1454)	(.2499)
Δr_{base}	.0346	−.0198	−.0516*	−.0819***	−.0235	−.0399**	.0133
	(.0297)	(.0259)	(.0309)	(.0266)	(.0240)	(.0221)	(.0155)
$\Delta r_{base} \times D^{PLB}_{f,t}$	.3650***	−.0339	−.1031***	−.0807***	−.1957***	−.0751**	−.1804
	(.0462)	(.0297)	(.0344)	(.0314)	(.0424)	(.0316)	(.1190)
Δr_{Eonia}	−.0842***	−.0012	.0311	.0070	−.0090	−.0081	−.0050
	(.0199)	(.0140)	(.0193)	(.0124)	(.0129)	(.0139)	(.0154)
$\Delta r_{Eonia} \times D^{PLB}_{f,t}$	.1631***	−.0380**	−.0445**	.0106	.0250	−.0081	−.1026
	(.0373)	(.0163)	(.0216)	(.0160)	(.0204)	(.0139)	(.0752)
$\Delta Tier1$	−.0935***	−.0520***	−.1194***	−.0243*	−.0247*	.0143	−.0327
	(.0150)	(.0119)	(.0184)	(.0122)	(.0137)	(.0118)	(.0187)
$\Delta Tier1 \times D^{PLB}_{f,t}$	.0489	.1134***	.1117***	.0405**	.0352	−.0618**	−.0657
	(.0636)	(.0152)	(.0242)	(.0190)	(.375)	(.0309)	(.1307)
ΔHHI	.0384***	.0104	.0064	−.0105	.0355***	.0111	.0563***
	(.0121)	(.0090)	(.0124)	(.0094)	(.0102)	(.0119)	(.0059)
$\Delta HHI \times D^{PLB}_{f,t}$	−.0344***	.0293***	.0252*	.0300***	−.0030	−.0122	−.0587***
	(.0124)	(.0103)	(.0133)	(.0103)	(.0141)	(.0120)	(.0061)
$D^{PLB}_{f,t}$	−.0018***	.0000	−.0005***	−.0004***	−.0004	−.0000	−.0005
	(.0001)	(.0001)	(.0001)	(.0001)	(.0003)	(.0001)	(.0006)
maturity FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	47035	48810	52366	45028	49785	37921	27797
R^2	.1433	.1047	.1475	.1322	.0985	.1900	.1117