Are Prices 'Sticky' Online? Market Structure Effects and Asymmetric Responses to Cost Shocks in Online Mortgage Markets

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Forthcoming in the *International Journal of Industrial Organization*

Abstract

We analyze daily mortgage rates posted by online lenders at the price comparison site, *Microsurf.* While cost shocks occurred almost daily in our sample, quoted mortgage rates are surprisingly rigid: Only 16 percent of the posted rates represent changes. However, firms that adjusted rates in response to cost shocks did so quite rapidly; about 98 percent of a cost shock was passed through within two days of the cost shock. Duration analysis reveals that the observed rigidity in rates systematically depends on market structure: Online mortgage rates are 30 to 40 percent more durable in concentrated markets than in markets where there are many competitors. We also find that rates posted online tend to exhibit downward stickiness; rate adjustments in response to cost increases are about twice the corresponding adjustments for cost decreases.

Keywords: mortgage rate, price adjustment, price rigidity, price dispersion.

JEL classification numbers: D43, L13, M3.

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We are grateful to Daniel Levy, Robert S. Chirinko, Igal Hendel, and the referees for helpful comments.

1 Introduction

Economists comparing the competitiveness of electronic and traditional market environments often argue that electronic commerce entails lower transaction costs. On the demand side, the cost to consumers of becoming informed in e-retail settings is low due to readily available online information and superior search capabilities.[1] These lower transaction costs and the globalization of markets may enhance competition and result in prices that more closely match the external economic environment. On the other hand, the fact that these new technologies permit firms to monitor rival's prices and to adjust prices in real time may lead to higher prices due to collusion.[2]

While a number of papers have documented that the Internet has yet to eliminate price dispersion (see Bakos (2001) and Smith et al. (1999) for surveys and Baye et al. (forthcoming) for an analysis of the impact of market structure on price dispersion), relatively little is known about the economic forces that induce firms competing in online markets to adjust their prices. Since it is arguably easier for firms to change online prices than to change price tags at brick-and-mortar outlets, one might expect prices posted in online markets to change very frequently in response to changes in marginal cost and other economic factors.

To examine price adjustment patterns in online markets, we assembled firm-level panel data consisting of daily observations on the rates charged by different online lenders for 30-year fixed-rate mortgages. The data were obtained from *Microsurf*, which is a price comparison site for mortgages. Mortgage providers submit their mortgage rate quotes, and terms and conditions for loan origination to *Microsurf* in real time. *Microsurf* publishes these rates along with other characteristics of loans and

[1] The order in which search results are presented to potential buyers online is also an important determinant of market competitiveness (See Arbatskaya, 2001). For an empirical analysis of consumer behavior on the Internet, see Brynjolfsson and Smith (2000a).

[2] The availability of information and short detection lags are some of the requirements for maintaining a cartel agreement.

lenders on its web site, and consumers may access this information free of charge. The data, which consist of firms' pricing decisions over the period April 30, 1998 through July 22, 1998, reveal considerable price dispersion. The range in interest rates charged – the difference between the maximum and minimum rate – exceeds 0.25 on all but one date in the sample. These price differences are not transient in nature – they are observed over time and do not "converge" to zero during the sample period. In short, dispersion in mortgage rates appears to be an equilibrium phenomenon among online lenders. As we discuss in the next section, these observations are consistent with a variety of theoretical models of online price dispersion, as well as levels of dispersion documented in online markets for books and electronic products.[3]

Since the persistence of price dispersion in online markets is well-documented in the recent literature, our aim in the present paper is to identify factors that influence firms to adjust their prices. This focus is motivated, in part, by the considerable variation observed in online lenders' decisions to adjust the mortgage rates posted at *Microsurf.* For instance, based on daily rates for 30 year fixed-rate mortgages listed at *Microsurf* over the three-month sample period, one lender (*Universal Mortgage Corporation)* never changed its posted rate, while another lender (*Custom Mortgage Corporation*) changed its rate about 70 percent of the time. Over the period, the 10-year T-Bond rate (a commonly used proxy for lenders' marginal cost of funds[4]) changed on over 87 percent of the days.

In Section 2 we show that a variety of different theoretical models predict that the frequency with which firms adjust their prices depends on structural variables, such as the number of competing firms, characteristics of the product, the frequency of cost changes, and the menu cost of adjusting prices. In Section 3 we describe our data and

[3]See, for example, Baye and Morgan (2001), Baye, Morgan, and Scholten (2004), and Brynjolfsson and Smith (2000b), among others..

[4]See, for example, Roth (1988).

explain why it is well-suited for an econometric analysis of the determinants of firms' decisions to adjust the prices posted on the Internet. Section 4 presents the results of our data analysis. The econometric analysis reveals that market structure is a critical determinant of the frequency with which online lenders adjust their rates: Rates are adjusted more frequently in markets with a large number of competitors and less frequently in markets where competition is less intense. Similar to recent studies by Peltzman (2000) and Borenstein et al. (1997) documenting asymmetric responses by traditional brick-and-mortar establishments, we find that online mortgage rates also respond more quickly to increases than to decreases in lenders' cost of funds. Section 4 offers concluding remarks.

2 Theoretical Considerations and Stylized Facts

Before turning to a formal presentation and analysis of the data, we briefly summarize some of the theoretical and empirical literature that is relevant for understanding price setting behavior at *Microsurf*. First, a number of models indicate that the price dispersion observed at *Microsurf* is consistent with equilibrium behavior, and that the likelihood a given firm offers the lowest price on a given date depends on the number of firms competing in the relevant market. For instance, clearinghouse models (cf. Rosenthal, 1980; Varian, 1980; and Baye-Morgan, 2001) assume that some or all consumers have access to a list of prices charged by different firms. In the present context, this amounts to assuming that at least some consumers observe the list of rates provided by *Microsurf* on any given day. A key implication of these models is turnover in the identity of the firm offering the lowest mortgage rate. The data we collected from *Microsurf* share this feature. Over 80 percent of the firms in our sample offered the lowest mortgage rate on at least one date in their local markets (states) during the three-month period. This high turnover in the identity of the firm offering the lowest mortgage rate is not consistent with firms maintaining the same relative position in the distribution of mortgage rates.

In addition to this existing literature on price dispersion, there are extensive theoretical and empirical literatures examining price rigidity in conventional retail markets. The empirical literature finds that prices in many markets are surprisingly rigid.[5] However, Levy et. al (1997) show that price rigidity varies considerably across markets, depending on the magnitude of menu costs. Specifically, in retail markets where legal restrictions require that a product's price be printed on each item, prices are adjusted less frequently than the prices of products exempt from the law. Therefore, price adjustment costs (menu costs) provide a compelling explanation for price rigidity. When firms incur significant costs to change their prices, prices are less responsive to changing market conditions.

In the online mortgage markets, menu costs are relatively small for lenders since they can change the rates posted at *Microsurf* with a few simple keystrokes. Moreover, the institutional setting at *Microsurf* provides lenders with an incentive to regularly (at least daily) update their rates: Lenders with the most up-to-date rate quotes are displayed at the top of the list of available rates. Any existing costs of price adjustment should then be due to the cost of gathering information regarding market fundamentals and making a pricing decision. In light of these low menu costs and lenders' incentives to adjust rates to move them at the top of the list, one might expect online lenders to frequently adjust their rates in response to changing market conditions. One might also expect there to be a willingness on the part of lenders to make very small changes in rates, which could only be justified in markets with

[5] For empirical evidence on price rigidity in retail trade see, for example, Kashyap (1995) and Warner and Barsky (1995); for evidence of price rigidity in the banking industry, see Neumark and Sharpe (1992) and Ausubel (1991).

insignificant menu costs.[6]

Lach and Tsiddon (1996) examine whether price adjustments in conventional retail markets are synchronized or staggered across products. For multi-product firms (or firms operating in a number of different markets), the costs of price adjustment affect the synchronization of price adjustments across markets. They find that firms synchronously adjust prices for the products they sell. Many lenders at *Microsurf* operate in a number of geographical areas (states). Our data permits us to examine whether this important finding extends to online markets.

Theories of price rigidity also indicate that market structure influences the probability that a firm changes its price. For instance, Akerlof and Yellen (1985) argue that the profits lost by failing to adjust price in response to a cost shock are lower in monopoly than in a Bertrand duopoly. Following this argument, Rotemberg and Saloner (1987) show that monopolies are less likely to adjust prices in response to cost changes than firms in duopoly markets. The empirical literature on the effects of market structure on price rigidity has also documented that the frequency of price adjustments is lower in more concentrated markets. For example, Hannan and Berger (1991) find that deposit interest rates at conventional banks are more rigid in concentrated markets, where market concentration is measured by the Herfindahl index.[7]

Our paper is also related to a number of studies in the macroeconomic literature that examine mortgage rate adjustments at the *aggregate* rather than firm level. For example, Allen et al. (1999) examine the relationship between weekly average

[6] In addition to the costs of price adjustment, the inflexibility of prices in response to cost or demand shocks has been explained in the literature by such factors as supply adjustment costs, inventories, long-term contracts, procyclical elasticity of demand, non-price market clearing, imperfect information about product characteristics, and by firms' conduct (e.g., price protection, breaks in collusion during periods of slack in demand.)

[7] An exception is Fisher and Konieczny (1995), who find that prices for city newspapers that face no competition are *less* rigid than the prices of oligopolistic newspapers.

mortgage rates and capital market rates.[8] Based on weekly data, they find that the speed of adjustment in the aggregate mortgage rate is much more rapid in the post-1981 period than in the pre-1981 period. Our analysis complements this macro approach by examining micro determinants (such as market structure) of individual online lenders' rate adjustments based on a cross section of daily firm-level data.

In short, economic models that closely match the "price-setting" environment at *Microsurf* predict not only that rates posted at *Microsurf* are dispersed – as they indeed are – but that the probability that a firm changes its rate on any given day will depend on whether costs changed that date, the number of competitors, and demand characteristics (including terms of the mortgage).

3 The Data

The theoretical and empirical papers discussed in the previous section suggest that the institutional environment and market structure are critical determinants of firms' pricing decisions. We begin by describing the institutional environment at *Microsurf*, which is an online price comparison site for mortgage rates.

Obtaining a mortgage loan for a property in a given state requires finding a lender that offers mortgages for property in that state. To obtain a list of lenders and rates for a given state, a borrower may simply click the state where the property is located (for example, Indiana) and *Microsurf* will return a list of lenders that offer mortgages for property in that state, along with the rates charged by these lenders. A mouse-click or toll-free phone call permits a borrower to lock-in the lowest rate. Lenders can update (in real time) information on the mortgage loans they offer; *Microsurf*

[8] See also Roth (1988). In addition, there is an extensive mortgage literature in real estate finance, dating back to Foster and Van Order (1984), which models mortgage default as a "put" option. For a survey of the option-pricing approach to mortgage valuation, see Kau and Keenan (1995).

promptly publishes the lenders' offers on its web site, with the most recently updated quotes displayed at the top of the list. *Microsurf* requires mortgage providers to include information about the qualifying ratios for the loan and the lock-in period. Therefore, in the trading environment of *Microsurf*, lenders face relatively low menu costs and consumers can easily become informed about mortgage characteristics and rates charged by different lenders.

The data, collected between April 30 and July 22 of 1998, include 9777 daily observations on the rates charged by 92 different lenders for a conventional conforming 30-year fixed mortgage with zero points in all states in the United States and in the District of Columbia.[9] Interestingly, not all lenders posted rates in all states, nor did all lenders update their rates daily. To avoid potential biases, only rates with time stamps corresponding with collection dates are included in the sample.[10]

As a proxy for lenders' costs of funds, we us daily yields on U. S. Treasury securities (henceforth, T-Bond Rates). Roth (1988) notes that the rate on 10-year T-Bonds is a good proxy for a lender's cost of funds on 30-year fixed-rate mortgages, since the average maturity of such mortgages is about 10 years.[11] Thus, our analysis includes specifications that use the 10-year T-Bond rate (and its lags) as a proxy for the common component of lenders' marginal cost. In addition, a number of authors have argued that lenders costs are a function of short, medium, and long-term Treasury rates. To account for the potential term structure effects in lenders' cost of funds,

[9]Mortgage rates correspond to the annual percentage rates (APR), the interest rates which reflect the annual cost of a mortgage, taking into account origination fees and other up-front charges. A point, equal to one percent of the loan amount, is paid by a borrower at mortgage closing. The data was gathered at the *Microsurf*'s Internet site (*http://www.microsurf.com*) between 10 and 11 P.M. daily, except for May 15, May 16, and July 6.

[10]As a practical matter, however, relatively few quotes were out of date. This likely stems from the following factors. First, we collected data at the end of each day. Second, lenders with the most up-to-date rates receive the benefit of being placed on top of the list. Finally, *Microsurf* warns consumers against relying on mortgage quotes that were not posted on the day of their search.

[11]A referee noted that an alternative measure of the cost of funds is the Fannie Mae Constant Maturity Debt Index Series. As one might expect given the collinearity in interest rates, the results reported below are robust to using this alternative measure of the cost of funds.

we also include specifications that incorporate three different T-Bond rates (1-year, 10-year, and 30-year) and their lags.[12] Our data permits us to disentangle changes in lenders' mortgage rates that are due to common cost shocks.

Table 1 provides summary information for the relevant data. The average mortgage rate in our data set was 7.4 percent, compared to an average 10-year T-Bond rate of 5.5 percent. Also included in Table 1 are summary statistics for indicator functions that take on a value of 1 if a lender's mortgage rate (or the T-Bond rate) changed on a given day and a zero otherwise. Notice that, on average, lenders changed rates only 16.1 percent of the time, even though the 10-year T-Bond rate changed 87.3 percent of the time. Thus, the mortgage rates posted at *Microsurf* do not change nearly as frequently as the firms' costs.

Table 1 also presents the descriptive statistics for such mortgage characteristics as lenders' required qualifying ratios and the length of the mortgage lock-in period. Lenders report two qualifying ratios a borrower must satisfy: the maximum allowable housing expense-to-income ratio (mortgage qualifying ratio) and the maximum allowable debt payment-to-income ratio (debt qualifying ratio).[13] For example, a pair of qualifying ratios $(0.28, 0.36)$ means that, to qualify for the posted rate, a borrower cannot spend more than 28 percent of her gross income on mortgage payments, and total debt payments cannot exceed 36 percent of gross income. In the sample, the mortgage qualifying ratio ranges from 0.28 to 0.36 and the debt qualifying ratio ranges from 0.36 to 0.45. Since qualifying ratios screen prospective borrowers accord-

[12] There is a strong correlation between movements in Treasury rates of different duration. For the sample period, the correlation coefficient is 0.92 between changes in 30-year and 10-year T-Bond rates and 0.80 between changes in 1-year and 10-year T-Bond rates.

[13] The mortgage qualifying ratio is the ratio of a borrower's monthly housing payments (mortgage principal payment, mortgage interest payment, property taxes, and homeowner's insurance) to the gross monthly income. The debt qualifying ratio is the percentage of a borrower's gross monthly income that would cover the borrower's monthly housing payments and any other monthly debt payments. The qualifying ratio is only a rough measurement of a borrower's credit-worthiness, and many other factors, such as the borrower's credit history, amount of down payment, and size of loan can affect a lender's decision on whether to approve a loan.

ing to their ability to repay the loan, one would expect higher qualifying ratios to be associated with a riskier pool of borrowers, and therefore higher quoted rates.

Lenders post not only a mortgage rate, but also the period of time that rate is "locked-in." On average, the duration of the lock-in period in the sample is 42.5 days. The longest period a consumer can lock-in to rate is 90 days, while the most common values for the lock-in period are 30 and 45 days.

While lenders may, in principle, change mortgage characteristics such as qualifying ratios and the length of the lock-in period in real time, there is virtually no variation over time in the characteristics of a particular lender's mortgages.[14] One possible explanation is that a lender's qualifying ratios are long-term decisions (quarterly or annual, for example) designed to shape the risk characteristics of the pool of mortgages as new (quarterly or annual) information is revealed about the number of defaults and portfolio risk. Given the relatively short span of our data (3 months), a particular lender's qualifying ratios are therefore less likely to change (as is indeed the case) than its quoted mortgage rate.

In addition to these variables that capture information about loan characteristics and the lenders' marginal cost of funds, the information from the *Microsurf* site permits us to construct a number of useful measures of market structure that reflect the underlying competitiveness of the various markets served. For instance, for each date we have information about the number of lenders offering mortgages in each state, which we refer to as the number of firms in the local market. On average, 4.8 firms list rates in each local market (state), with the number of firms ranging from 1 to 15. The number of lenders listing rates in a given state tends to vary over time. Table 1 summarizes a dummy variable for local markets with 1 to 5 firms. Notice

[14]Mortgage ratios change less than 0.3 percent of time in the sample. As for the lock-in, about 0.03 percent of mortgage quotes are associated with a change in the lock-in period. Hence, compared to changes in mortgage rates, mortgage characteristics are very rigid.

that 67.5 percent of the rates were posted in markets where 1 to 5 lenders listed their rates. The distribution of firms in that range is fairly uniform, from 9.8 percent where only 1 firm listed a price to 13.9 percent where 5 firms listed a rate.

Many lenders listed rates in several markets (states). To the extent that multi-market contact impacts lender decisions, we measure this overlap with the dummy variable "0 to 10 Distinct Global Rivals." This dummy variable takes on a value of 1 if the firm that posted a rate in a given market competed on that date with up to 10 different firms (either in the same market, or in different markets). On average, lenders compete against 14.6 different lenders globally.

Another proxy for market power is markup, which is known to be related to the Herfindahl index in a variety of oligopoly settings.[15]. We define the variable *Markup* as the difference between the mortgage rate a lender posts and the 10-year T-Bond rate, as a percentage of the T-Bond rate. Since the T-Bond rate is a proxy for the common component of lender costs, this measure proxies market power enjoyed by a lender (but ignores any unobservable differences in costs), and thus provides a gauge of a lender's ability to charge supra-competitive prices. Our data reveal that markups vary considerably in Internet mortgage markets, from about 22 percent to 44 percent. These differences can be attributed, for example, to differences in market concentration, non-price aspects of mortgages and other product heterogeneities, as well as unobserved heterogeneity in lender costs. In some of the econometric specifications presented below, we include *Markup* as a crude control for otherwise unobservable mortgage characteristics that contribute to lenders' market power.

Finally, there is considerable heterogeneity among firms in the timing of rate adjustments, as well as their propensities to change posted rates. To illustrate, consider Figure 1, which depicts the timing of rate changes by two prominent online lenders in

[15] See, for instance, Dansby and Willig (1979).

Texas: *Access National Mortgage* and *MEC-Online*. Notice that on several occasions, one lender changed its rate while the other did not change its rate over the period surrounding the rate change. More generally, about 8 percent of the lenders in our sample never adjusted their mortgage rates, while 9 percent of the lenders changed their rates more than 50 percent of the time.

We believe these data on online mortgage rates are well-suited for analyzing the factors that affect lenders' price adjustment decisions. Our data span markets in different states in the United States, with differing numbers of local and global competitors; we enjoy a panel data of daily observations at the level of individual online lenders. Thus, we are in a position to examine empirically the determinants and nature of price adjustments in the online market for mortgages.

4 Empirical Analysis

In this section, we use the above data to examine the impact of market structure and other economic factors on lenders' propensities to change posted mortgage rates, the duration of posted mortgage rates, and the responsiveness of posted rates to cost shocks.

4.1 The Propensity to Change Posted Rates

From the theoretical considerations in Section 2, one would expect a lender's decision to adjust the rate it charges in state s on date t to depend on whether its marginal cost of funds changed on that date, on the number of local and global competitors the firm faces on that date, and such mortgage loan characteristics as the mortgage qualifying ratio, debt qualifying ratio, and the number of days the mortgage rate is locked-in.

When lenders' costs of funds change, they are more likely to adjust their mortgage rates. While theory indicates that lenders are less likely to adjust rates in more concentrated local and/or global markets, preliminary data analysis reveals that lenders tend to adjust their rates synchronously in all the states in which they post rates on a given day. This suggests that a lender's decision to change its rate on a given date may be more affected by global rather than local competition. One would also expect lenders with high qualifying ratios to set a higher mortgage rate to compensate for the increase in the risk of lending money to a broader pool of borrowers.[16] Adverse selection and moral hazard problems that arise from the asymmetry of information can be potentially more prevalent when lenders set high qualifying ratios. To the extent that these lenders are less selective and therefore attract a more risky clientele, one might expect them to build a sizeable cushion into their rate, thereby eliminating the need for frequent rate changes that could exacerbate adverse selection problems. One might, therefore, expect the mortgage rates of such lenders to be more rigid. Finally, one would expect lenders with longer lock-in periods to change rates less frequently, as their posted rates would have a cushion built in to deal with random day-to-day changes in the business environment that will naturally occur during the lock period.

We use the data described in Section 3 to test these hypotheses. Table 2 presents results from binary change models in which we estimate the relationship between *Change*, an indicator variable for the incidence of a rate change by a lender[17], and a linear function of the explanatory variables. These regressions capture the impact of changes in explanatory variables on lenders' propensities to change their posted rates;

[16] On the other hand, if less credit-worthy consumers are also the ones who are more price-sensitive, firms may have an offsetting incentive to charge them a lower rate. This means that the relationship between the qualifying ratios and mortgage rates could be ambiguous.

[17] $Change_{ist}$ equals one if lender i's mortgage rate has changed on date t in state s, compared to the mortgage rate advertised by the lender in the same state on an earlier date in the sample, and zero if the rate has not changed.

negative coefficients imply that an increase in the explanatory variable decreases the likelihood that a lender changes its rate. We report estimated coefficients and their p-values for a simple OLS and two Logit specifications, as well as the implied marginal effects (at the mean) for each logit specification. Since the dependent variable is an indicator function, the limited dependent variable (Logit) specifications are better suited for the analysis; the simple OLS specification is reported in column 1 to merely serve as a point of reference.

In addition to the explanatory variables of interest listed in Table 2, all specifications include controls for day-of-week effects and binary cost-of-fund effects. The former control for potential heterogeneity in firms' propensities to change mortgage rates on different days of the week (e.g., Monday or Friday effects). The binary cost-of-funds effects use indicator variables for changes in the 10-year T-Bond rate (and 5 lags) as a proxy for cost shocks experienced by lenders. Specifications with binary term structure effects add indicator variables for changes in 1-year and 30-year T-Bond rates (and 5 lags of each), and therefore represent a more general proxy for shocks to lenders' marginal cost of funds.

Notice that the results summarized in Table 2 tend to be robust across different specifications.[18] The signs of the parameter estimates are broadly consistent with what one would expect based on the theories discussed earlier: Firms' operating in more concentrated markets or offering mortgages with more liberal characteristics (qualifying ratios or lock-in periods) tend to have lower propensities to change their rates.

The most interesting aspect of the results in Table 2 is the light it sheds on the impact of market structure on lenders' decisions to change mortgage rates. Consider

[18]In an earlier version of this paper, we showed that the results are also robust to the exclusion day-of-week fixed effects, the exclusion of lagged values of the various T-Bond rates, and differing bin sizes for the number of distinct global and local rivals.

first the simple OLS regressions in column 1. Firms that face 10 or fewer global rivals are less likely to change rates than those who face more than 10 global rivals. Thus, higher global concentration results in more rigid prices. For the specifications reported in Table 2, a firm that faces 10 or fewer different global rivals is 4.7 percent (OLS 1) to 6.0 percent (Logit 2) less likely to change its rate on a given day than a firm facing more global rivals. Furthermore, in all specifications the estimated coefficients are statistically significant at the 10 percent level. Thus, there is strong evidence that prices tend to be more rigid in markets where firms face less global competition.

The signs of the estimated coefficients for the effects of local competition tell a similar story, although the marginal effects (and their significance) are lower. For instance, in the most general specification (Logit 2), the estimates imply that a firm that faces 5 or fewer local rivals is 1.7 percent more likely to change its posted rate on a given day. This effect, which is statistically significant at the 10 percent level, is three times smaller than the corresponding effect of global competition.

Finally, the results in Table 2 indicate that lenders with more liberal loan characteristics are less likely to change their rates. While the inverse relationship between the qualifying ratios and changes in mortgage rates holds in all cases, the effect is statistically significant at the 10 percent level only for the debt qualifying ratio in the Logit 2 specification. The estimated marginal effect of -1.068 implies that a firm having a debt qualifying ratio that is 5 percentage points higher than the mean is 5.3 percent less likely to change its rate. Finally, notice that in all specifications, there is a negative and statistically significant relation between the days a lender locks in a rate and its propensity to change rates. A firm that offers a lock that is 10 days longer than the average lock is about 2 percent less likely to change its rate.

4.2 The Duration of Posted Rates

In order to examine the robustness of the above findings, we also use duration analysis. Following this approach, we look at the impact of market structure and mortgage characteristics on the length of time between mortgage rate adjustments by a lender. In this case, the dependent variable is the number of days between consecutive changes in a lender's mortgage rate. To account for the fact that the first and the last date on which a lender posts its mortgage rate do not coincide with the sample period, we treat observations as censored.

Figure 2 depicts the non-parametric Kaplan-Meier survival functions estimated at the means of the sample for markets with few and many rivals. The horizontal axis measures the duration of mortgage quotes (in days), while the vertical axis measures the proportion of posted rates that have survived (not changed) for a given number of days. The fact that the dashed survival curve for lenders facing 10 or fewer global rivals lies above that for lenders facing more than 10 rivals suggests that rates are more durable in more concentrated markets. To formally test this hypothesis, we performed nonparametric rank tests. The log-rank test as well as the Wilcoxon (Breslow-Gehan) test confirm that market concentration – both global and local – has a positive and statistically significant effect on the duration of mortgage rate quotes.[19]

We also performed parametric tests based on maximum likelihood estimates from exponential and Weibull duration models. The distributional assumptions underlying these models have differing implications for the duration-dependence of firms' posted rates; the exponential specification implies a constant hazard function and hence no

[19] The χ^2-statistics and corresponding p-values for the test for equality of survival functions for markets with 10 or fewer global rivals and markets with more than 10 global rivals are $\chi^2_{(1)} = 8.26$ ($p = 0.004$) and $\chi^2_{(1)} = 5.21$ ($p = 0.025$). The corresponding statistics for the effect of local competition are similar: $\chi^2_{(1)} = 6.76$ ($p = 0.009$) and $\chi^2_{(1)} = 5.02$ ($p = 0.025$).

duration dependence, while the Weibull specification allows for positive or negative duration dependence.[20] All specifications include controls for day-of-week effects, as well as cost-of-fund effects. Here, cost-of-fund effects reflect levels of change in the 10-year T-Bond rate (and 5 lags); specifications with term structure effects add levels of change (and 5 lags) in 1-year and 30-year T-Bond rates.

Table 3 reports estimated hazard ratios and their p-values. The estimated hazard ratios are related to both the propensity of lenders to change mortgage rates, as well as the expected duration of a given rate quote. Specifically, hazard ratios below unity indicate that an increase in the explanatory variable decreases the conditional probability (hazard) that a lender adjusts its rate, and hence increases the implied length of time between rate adjustments (rate quotes are more durable or "rigid").

A comparison of the estimated log-likelihood functions reveals that Weibull model provides a slightly better fit for the data. The shape parameter in the Weibull model is negative and significant, suggesting a slightly negative duration dependence for our data. However, the empirical findings regarding the impact of the explanatory variables are very similar for the two models. The estimated hazard ratios in Table 3 broadly suggest that firms operating in more concentrated markets or offering mortgages with more liberal characteristics tend to have more durable rates. However, only the global measure of competition and the days locked-in are statistically significant at the 10 percent level.

Table 4 summarizes the implications of the estimated duration models for the duration of posted mortgage rates. The mean duration of mortgage rates across all markets varies from 24.5 days (for the exponential specification without term structure effects) to 28.7 days (for the Weibull specification with term structure effects).

[20] We also ran regressions based on the distribution-free Cox proportional hazards model. The Cox model does not make any distributional assumptions on the baseline hazard function, and yields estimates similar to those reported in Table 4.

Mean durations are consistently (and significantly) lower in markets with more than 10 global rivals, where mortgage rates remain unchanged for 22.3 to 25.5 days, on average. In contrast, in more concentrated markets, the mean duration ranges from 29.1 to 35.4 days. While the implied median durations are somewhat lower, they exhibit a similar pattern. In short, the duration of posted mortgage rates is 30 to 40 percent longer in more concentrated markets, depending on the specification. As shown in Figure 3, a similar pattern is observed when one examines the estimated hazard functions. This graph implies that, after allowing for duration dependence and controlling for other factors, the conditional probability of rate changes is uniformly higher in more competitive markets and uniformly lower in more concentrated markets.

Finally, all estimated duration models imply that mortgage rates of firms offering longer lock-in periods are significantly more durable. For instance, in the Weibull specification with term structure effects, the estimated mean duration of mortgage rates increases from 23.7 days for a 30-day lock-in period to 26.4 days for a 45-day lock-in period (a 10-percent increase in rate durability).

4.3 Responses to Cost Shocks

Up to this point, our analysis has focused on the rigidity of lenders' rates. While we have examined the determinants of *duration* and lenders' *propensities* to change online rates, we have yet to discuss the *magnitude* and speed of adjustment of posted rates to changes in the levels of lenders' costs of funds.

Table 5 illustrates that, similar to existing studies of traditional markets,[21] price adjustments in online markets exhibit asymmetries in the magnitude of upward and

[21] See, for example, the papers by Allen et al. (1999) and Hannan and Berger, (1991). For an alternative view, see Carlton (1986).

downward adjustments in mortgage rates. Conditional on a price change, lenders were almost as likely to increase rates as decrease rates. However, the associated upward price adjustments were on average larger in magnitude than downward adjustments (0.147 and -0.122 percent, respectively). Upward price adjustments are also more dispersed, ranging from 0.001 to 0.706, with a standard deviation of 0.098, compared to downward price adjustments, which range from -0.001 to -0.400, with a standard deviation of 0.043. This difference in the magnitude of upward and downward adjustments in mortgage rates is statistically significant at the 1 percent level. Also note that we observe very small changes in mortgage rates, which is consistent with the notion that menu costs are indeed very small in the online mortgage markets.

There is an extensive microeconomics literature documenting asymmetric responses of prices in conventional markets to cost shocks; see Peltzman (2000) and Borenstein et al. (1997) for a discussion of this line of research.[22] We follow the approach of these authors and examine a variety of distributed lag models to explore determinants of changes in *levels* of mortgage rates. These results are presented in Table 6, and reveal that the patterns displayed in Table 5 persist even after controlling for potential heterogeneities (state and firm fixed effects), mortgage characteristics, and market structure effects.

The first three columns of Table 6 present estimates for symmetric specifications where it is assumed that firms respond symmetrically to increases and decreases in their cost of funds (the 10-year T-Bond rate). Results are fairly consistent across all specifications, regardless of whether one controls for market structure, mortgage characteristics and firm/state heterogeneities. For example, in our most general symmetric response model (Fixed Effects 1), a 100 basis point increase in the cost of funds

[22]For a macroeconomic approach, see the studies by Allen et al. (1999) and Haney (1988) who also find asymmetry in the adjustment of traditional mortgage rates to shocks in capital markets.

leads to an immediate 54.7 basis point increase in mortgage rates, a 25.6 basis point increase the following day and a 17.9 basis point increase the next day. The cumulative response after two days (summarized in Table 7) is 98.2 basis points.

The second three columns of Table 6 allow for asymmetric responses. Notice that in all specifications, increases in the cost of funds have a greater impact on mortgage rates than do decreases. For instance, in our most general asymmetric specification (Fixed Effects 2), a 100 basis point increase in the cost of funds results in a concurrent increase in mortgage rates of 79.3 basis points, while a 100 basis point decrease in the cost of funds results in only a 24.2 basis point reduction in mortgage rates. In all specifications, these responses are statistically different from one another for concurrent, one-lagged and two-lagged changes, and responses are larger for cost increases than cost decreases. These results are robust to a variety of controls, dummy variables, and lag specifications. As shown in Table 7, the cumulative responses of mortgage rates to cost changes are greater for cost increases than cost decreases.

We also ran a variety of regressions to explore whether these asymmetric responses might be more prevalent in concentrated markets. Similar to Peltzman (2000), we found no evidence of a systematic relationship between the asymmetry in rate adjustments and market structure. Our finding that online markets exhibit asymmetries similar to those documented in traditional brick-and-mortar markets suggests that the asymmetric price responses are probably not driven by menu costs or similar frictions. These are virtually zero in online mortgage markets, yet we find asymmetric responses comparable to those found in studies of traditional markets.

As noted by Peltzman (2000), there are no well-established theoretical explanations for asymmetric responses of prices to changes in costs, so any attempt to explain the observed asymmetries will be speculative at best. One possibility, suggested by Allen et al. (1999), is that lenders' risk premia change asymmetrically with changes in their costs of funds. While these authors argue that such asymmetries could stem from the asymmetric impact of lower mortgage rates on pre-payment (refinance) risk, other channels may also lead to asymmetric changes in risk premia (and hence, asymmetric responses to cost shocks). For instance, changes in lenders' rates will generally change the pool of borrowers, potentially changing the nature of adverse selection. To the extent that the severity of adverse selection problems depend on the level of mortgage rates, the risk premia associated with rate increases may well differ from those for rate decreases.[23] Alternatively, lenders may respond asymmetrically to cost changes in an attempt to mitigate adverse selection problems.

Another potential explanation, which we believe is particularly relevant in online mortgage markets where consumers can easily monitor lenders' rates, stems from the differing effects of rate increases and decreases on the incentives of existing customers to renegotiate their loans. Other things equal, lenders may be more reluctant to reduce rates because doing so might induce existing borrowers (who are already paying a higher rate) to refinance at the lower rate. Likewise, rate reductions might induce customers who have locked-in to higher rates—but whose applications are still "in process"— to "back out" in an attempt to obtain more favorable rates.

5 Conclusion

This paper represents a first attempt to examine the determinants of firms' decisions to change prices in online markets. Our analysis, based on nearly 10,000 rate quotes from *Microsurf* (an Internet site that provides comparative information about the mortgage rates offered by different lenders in all 50 states and the District of Columbia), indicates that market structure is an important determinant of lenders'

[23] See, for example, Stiglitz and Weiss (1981).

decisions to adjust rates.

The answer to the question "Are prices sticky online?" is largely a matter of perspective. On the one hand, while lenders' cost of funds changed on more than 87 percent of days in our sample, lenders' changed their posted mortgage rates only 16 percent of the time. In addition, the median duration of quoted mortgage rates is between 16.6 and 19.2 days. In this sense, prices appear to be quite rigid in online markets. On the other hand, lenders who changed their rates passed through about 98 percent of cost changes to consumers within 2 days. In this sense, prices are much less sticky than at traditional retail outlets (see Peltzman, 2000). Thus, the evidence suggests that while firms do not change rates very frequently, those firms that do change rates tend to adjust them rapidly.

More importantly, the evidence suggests that online prices are more rigid in concentrated markets. In particular, lenders are about 5 or 6 percent more likely to change rates in concentrated markets than in more competitive markets. Duration analysis revealed that mortgage rates are between 30 and 40 percent more durable in concentrated markets. While our finding that rates are less flexible in concentrated markets is consistent with theories of price rigidity, an important puzzles remains: Why is a high degree of price rigidity and asymmetry observed in online mortgage markets, where menu costs and other frictions are virtually zero?

Finally, similar to recent studies of conventional markets, we find that online mortgage rates are more responsive to cost increases than cost decreases, with cost increases being passed on to consumers about twice as quickly as cost decreases. While we have provided some speculative arguments regarding factors that might contribute to the observed asymmetries, further theoretical work in this area is needed.

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Table 1: Summary Statistics

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Mortgage Rate (30 Yr. Fixed Annual Percentage Rate)	7.369	0.128	6.987	7.967
T-Bond Rate (10 Yr. Fixed)	5.526	0.093	5.380	5.790
Indicator for Change in Mortgage Rate	0.161	0.368	0	1
Indicator for Change in T-Bond Rate (10 Yr. Fixed)	0.873	0.333	0	1
Lender's Markup	0.333	0.034	0.224	0.437
Lender's Mortgage Qualifying Ratio	0.309	0.025	0.280	0.360
Lender's Debt Qualifying Ratio	0.376	0.015	0.360	0.450
Number of Days Locked in to Rate	42.511	13.362	30	90
Number of Firms in Local Market	4.823	3.005	1	15
Number of Distinct Global Rivals	14.585	9.102	0	45
0 to 10 Distinct Global Rivals	0.399	0.490	0	1
1 to 5 Firms in Local Market	0.675	0.468	0	1

Total Number of Mortgage Rates Observed: 9777

Table 2: Impact of Market Structure and Mortgage Characteristics on a Firm's Propensity to Change its Quoted Mortgage Rate

Parameter	Binary Change Models†							
	OLS 1		Logit 1			Logit 2		
	Coef.	***p-value***	***Coef.***	***p-value***	***Marg. Effect***	***Coef.***	***p-value***	***Marg. Effect***
0 to 10 distinct global rivals	-0.047	0.000	-0.368	0.000	-0.054	-0.404	0.000	-0.060
1 to 5 firms in the Local Market	-0.012	0.180	-0.084	0.189	-0.012	-0.116	0.081	-0.017
Mortgage qualifying ratio	-0.317	0.329	-2.384	0.291	-0.352	-0.797	0.725	-0.119
Debt qualifying ratio	-0.350	0.538	-2.729	0.494	-0.403	-7.160	0.074	-1.068
Days Locked-in to Rate	-0.002	0.000	-0.016	0.000	-0.002	-0.016	0.000	-0.002
Day-of-Week Fixed Effects	Yes		Yes			Yes		
Binary Cost of Fund Effects	Yes		Yes			Yes		
Binary Term Structure Effects	No		No			Yes		
Log-Likelihood			-3482			-3227		

† The binary change models use zero-one variables to measure changes in mortgage rates and changes in the cost of funds. For example, the dependent variable is a zero-one variable that equals one if firm i changed its mortgage rate on date t in state s, and equals zero otherwise. Reported standard errors are Hubert-White (corrected) standard errors. Marginal effects for the four Logit specifications are calculated at the mean of the sample.

Table 3: Impact of Market Structure and Mortgage Characteristics on Duration of Quoted Mortgage Rates

Parameter	Duration Models††							
	Exponential		Weibull Duration 1		Exponential		Weibull Duration 2	
	Hazard Ratio	***p-value***	***Hazard***	***p-value***	***Hazard Ratio***	***p-value***	***Hazard***	***p-value***
0 to 10 distinct global rivals	0.670	0.000	0.682	0.000	0.618	0.000	0.628	0.000
1 to 5 firms in the Local Market	1.008	0.917	1.006	0.935	0.975	0.736	0.976	0.739
Mortgage qualifying ratio	0.029	0.170	0.043	0.198	0.415	0.726	0.427	0.724
Debt qualifying ratio	0.660	0.930	0.443	0.857	0.002	0.155	0.002	0.146
Days Locked-in to Rate	0.981	0.000	0.981	0.000	0.979	0.000	0.979	0.000
Day-of-Week Fixed Effects	Yes		Yes		Yes		Yes	
Cost of Fund Effects	Yes		Yes		Yes		Yes	
Term Structure Effects	No		No		Yes		Yes	
Log-Likelihood	-2240		-2234		-2149		-2147	

†† The dependent variable is the number of days firm i has kept its mortgage rate fixed on date t in state s. Reported standard errors are Hubert-White (corrected) standard errors.

Table 4: Impact of Market Structure on Duration of Mortgage Rates

Duration Model	Term Structure Cost Effects?	Market Structure	Implied Estimates		
			Hazard Rate (Asymptotic SE)	Mean Duration	Median Duration
Exponential	No	>10 Rivals	0.056 0.008	22.3	15.5
		≤ 10 Rivals	0.044 0.007	29.1	20.2
		All Markets	*0.052* *0.007*	*24.5*	*17.0*
Weibull	No	>10 Rivals	0.070 0.010	23.2	15.1
		≤ 10 Rivals	0.055 0.009	30.3	19.8
		All Markets	*0.065* *0.009*	*25.5*	*16.6*
Exponential	Yes	>10 Rivals	0.056 0.009	24.6	17.1
		≤ 10 Rivals	0.041 0.008	34.1	23.7
		All Markets	*0.050* *0.009*	*27.7*	*19.2*
Weibull	Yes	>10 Rivals	0.064 0.011	25.5	17.0
		≤ 10 Rivals	0.048 0.009	35.4	23.6
		All Markets	*0.058* *0.010*	*28.7*	*19.2*

Table 5: Levels of Rate Changes

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Level of Change in Mortgage Rate	1512	0.011	0.154	-0.400	0.706
Absolute Value of Change in Mortgage Rate	1512	0.134	0.076	0.001	0.706
Level of Increase in Mortgage Rate	746	0.147	0.098	0.001	0.706
Level of Decrease in Mortgage Rate	766	-0.122	0.043	-0.400	-0.001

Table 6: Symmetric and Asymmetric Responses of Mortgage Rates to Changes in Costs

The dependent variable is the value of change in a firm i's mortgage rate on date t in state s. Reported standard errors in OLS regressions are Hubert-White (corrected) standard errors.

Parameter	Symmetric Response						Asymmetric Response					
	OLS 1		OLS 2		Fixed Effects 1		OLS 3		OLS 4		Fixed Effects 2	
	Coef.	***Std. Err.***	***Coef.***	***Std. Err.***	***Coef.***	***Std. Err.***	***Coef.***	***Std. Err.***	***Coef.***	***Std. Err.***	***Coef.***	***Std. Err.***
Change in T-Bond Rate	0.338*	0.024	0.407*	0.025	0.547*	0.025						
Change in T-Bond Rate Lagged 1 Day	0.150*	0.021	0.189*	0.021	0.256*	0.022						
Change in T-Bond Rate Lagged 2 Days	0.100*	0.019	0.134*	0.019	0.179*	0.019						
Increase in T-Bond Rate							0.615*	0.046	0.646*	0.049	0.745*	0.047
Decrease in T-Bond Rate							0.074*	0.034	0.190*	0.037	0.353*	0.035
Increase in T-Bond Rate Lagged 1 Day									0.216*	0.048	0.304*	0.048
Decrease in T-Bond Rate Lagged 1 Day									0.138*	0.038	0.181*	0.037
Increase in T-Bond Rate Lagged 2 Days									0.117*	0.038	0.070**	0.037
Decrease in T-Bond Rate Lagged 2 Days									0.122*	0.035	0.250*	0.035
Other Controls:												
Day-of-Week Fixed Effects	Yes		Yes		Yes		Yes		Yes		Yes	
2 Date Fixed Effects & Trend	Yes		Yes		Yes		Yes		Yes		Yes	
Market Structure & Mortgage Characteristics	No		Yes		Yes		No		Yes		Yes	
State & Firm Fixed Effects	No		No		Yes		No		No		Yes	
R-Square	0.27		0.30		0.37		0.26		0.31		0.37	

* Denotes significance at the 5 percent level.
** Denotes significance at the 10 percent level

Market structure controls include dummy variables for 0 to 10 distinct global rivals, 1 to 5 firms in the local market, and lender's markup. Date fixed effects include dummy variables for observed structural changes on May 20, 1998 and for dates after May 20, 1998.

Table 7: Cumulative Response of Quoted Mortgage Rate to Cost Changes (Based on General Models with Fixed Effects)

	Symmetric Response	Asymmetric Response	
		Cost Increases	Cost Decreases
Immediate	0.547	0.745	0.353
1 Day	0.804	1.049	0.534
2 Days	0.982	1.119	0.784

Figure 1: The Timing of Rate Changes for the Two Largest On-line Lenders in Texas

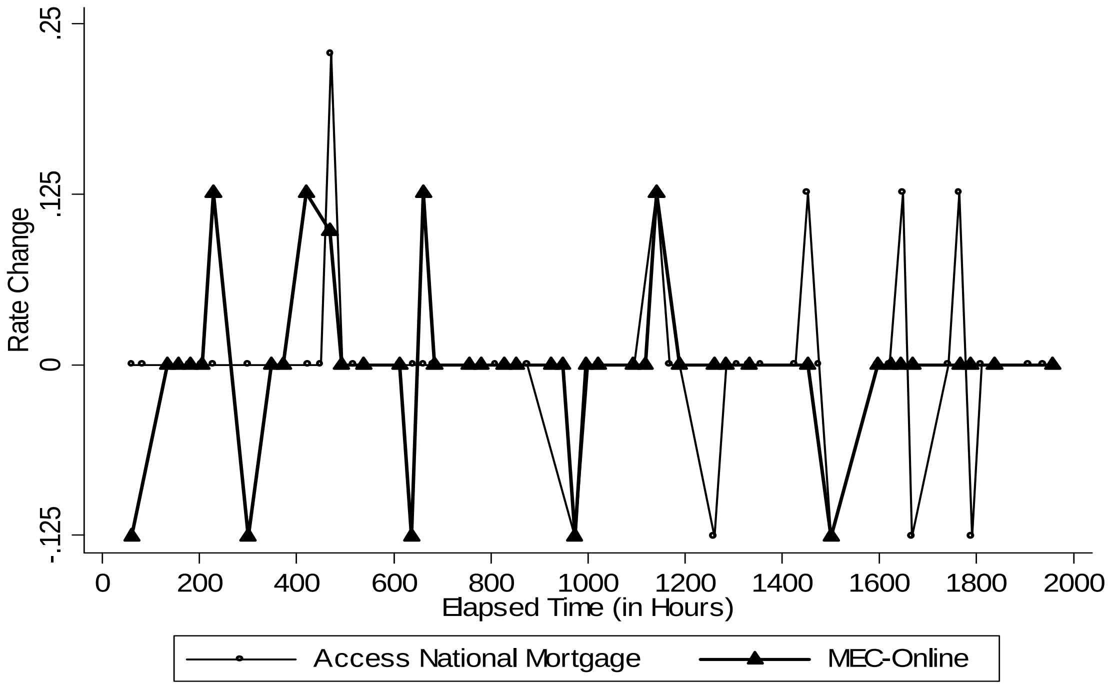

Figure 2: Kaplan-Meier Survival Curve

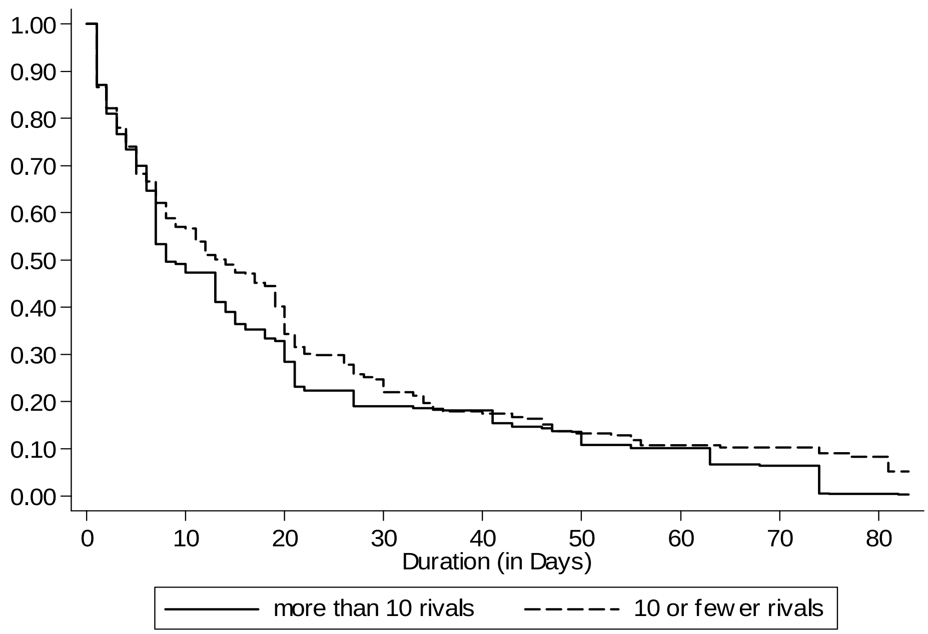

Figure 3: Estimated Hazard Functions: Weibull with Term Structure Effects