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Monetary Transmission to UK Retail Mortgage Rates before and after August 2007 *

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Abstract

This paper investigates the transmission from UK policy and a range of wholesale money market rates to retail mortgage rates using the long-run estimator proposed by Phillips and Loretan (1991), with a single-equation error correction model (SEECM) framework, from 1995 to 2009. I document the economy-wide effect of the financial market turmoil since August 2007, and show how this has altered long- and short-term relationships. In the long-run there is evidence of a contrast between the discounted mortgage rates that banks may use to initially attract customers, and standard variable rates, with pass-through complete for the former but not for the latter. For fixed rate mortgages, pass-through is generally complete. Since the crisis, for eight of the seventeen estimated relationships I find strong evidence in the long-run of both a significant jump in equilibrium spreads, and a fall in pass-through, whilst in the short-run there is a considerable weakening of the process that re-adjusts retail rates back towards their equilibrium with the money market. Although I do not find strong statistical evidence for an asymmetric re-adjustment process before August 2007, retail mortgage rates generally take considerably longer to move back towards their equilibrium with wholesale rates during times when they are relatively expensive. These results add to previous studies by showing that the UK retail banking sector is imperfectly competitive at the aggregate level, and also suggest that discounted rates are used as a highly competitive loss-leader product.

Key Words: Mortgage Rates, Monetary Transmission, Error Correction Model

JEL References: E43, E52

*I am grateful for helpful comments made by Stephen Millard at the Royal Economic Society Conference 2010 . Any errors remain mine.

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1 Introduction

It is widely acknowledged (see for example Goodhart (2008) and Buiter (2007)) that 9th August 2007 was the beginning of the global financial crisis. In the UK interbank money market spreads jumped (see figure 1), and although Northern Rock did not approach the Bank of England as lender of last resort until September, its sustainability was already in serious doubt. As time passed and more events unfolded, many previously stable interest rate relationships were affected in the UK, and it became almost impossible for net borrowers to raise funds on the wholesale money markets

Against this background, this paper analyses how these events have altered the transmission from UK policy and a range of wholesale money rates to retail mortgage rates. Although many previous studies have examined the channel from central bank policy to consumer mortgage payment flows, and hence to the real economy, none have yet documented the post-August 2007 effect (henceforth referred to as the crisis period).

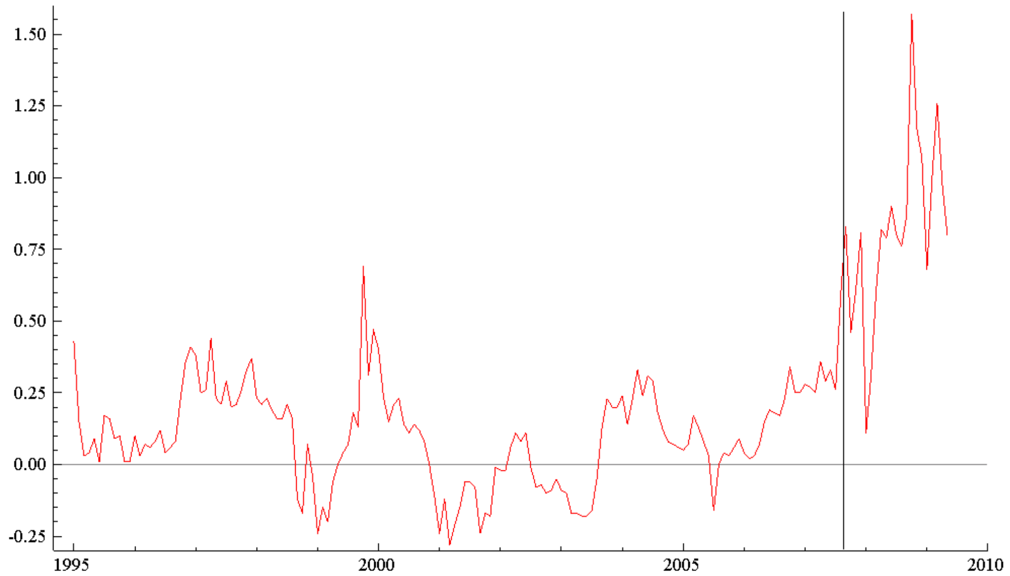


Figure 1: Spread of LIBOR (3 month) over Policy Rate. Line indicates August 2007.

I contribute to the literature by applying an econometric strategy whose theory is established in Phillips and Loretan (1991), and which is applied in Liu et al. (2008). Whereas Liu et al. (2008) looks at how relationships have changed since the introduction of inflation targeting in New Zealand, their paper provides a strong rationale for using this method (henceforth referred to as the P-L method) in a similar setting. Specifically, we have strong *a priori* evidence for three features that I maintain as working assumptions: Firstly, although imperfections in the banking sector may cause sluggish adjustment to wholesale changes, future expectations of wholesale rates are also likely to be important determinants of retail rates (see appendix F outlining a conceptual model proposed by Mizen et al. (2004)). If so then estimates of long-run relationships are biased using the standard Engle-Granger procedure, an issue that is resolved by the P-L method. Secondly, interdependence in general equilibrium implies that retail bank rate changes should eventually affect the real economy, and hence feed back to policy and money market rates. This reverse feedback however is likely to be neither relatively strong, nor relatively fast, and so a natural approach to estimating short-run relationships in the literature has been to assume a partial equilibrium with a single-equation error correction model (SEECM). The assumptions behind this approach are also covered by Liu et al. (2008).

Many studies have already looked at how retail bank rates react to monetary policy in the UK. Early work in this area focused on the question of whether the central bank was able to alter the cost of retail credit in the long-run. Dale and Haldane (1998) found that changes in bank rates actually overshot changes in the policy rate, whilst Mariscal and Howells (2002) used an error correction model to examine the impact of monetary policy on *relative* borrowing and lending rates. On finding solid long-run relationships between policy and individual rates, but not on differentials, they argued that monetary policy was therefore unlikely to be effective in altering economic activity through this channel.

The most prolific contributor to this literature is Shelagh Heffernan, with a series of papers which take as their starting point the observation that retail banking is subject to imperfections which delay and obscure transmission. In theory, profit maximising financial intermediaries working under perfect competition with complete information and no adjustment costs should fully pass changes on, symmetrically and instantaneously. Instead there may be oligopolistic collusion between banks; dynamic exploitation of consumer inertia; sunk and menu costs; and the possibility of endogenous default (where an increase in mortgage payments may lead to an increase in the probability of default, and hence alter revenue as a function of rates). Any one of these factors alone could lead to sluggish and asymmetric adjustment.

In Heffernan (1997) an error correction approach is applied to monthly data from 1986-93 on generic deposit and loan rates, showing that there are considerable differences in rate-setting behaviour between banks, which exhibit many features of imperfect competition. Similar studies, with similar methodologies and findings are later applied in different contexts: Heffernan (2006) analyses small business loans, and Fuertes and Heffernan (2006) disaggregates both between and within banks. The possibility of a *non*-linear re-adjustment process is allowed for in Fuertes et al. (2006) and Fuertes et al. (2008). These studies consider the increasingly popular relaxation of the classic, constant and linear error correction model, into richer specifications that allow the error correction term to vary over time. For a comprehensive background to these approaches is given by Tong (1993) and Franses and Van Dijk (2000). For threshold autoregressive models (TAR), once a chosen variable crosses a threshold, the error correction mechanism may switch. When the error-correction term itself is the threshold variable, they are known as self-exciting threshold autoregressive models, or SETARs (for an evaluation of their performance see Clements and Smith (1999)). The assumption of a discrete switch can also be relaxed so that it may smoothly move across a threshold in smooth transition autoregressive models, STARs (for an application see Liu (2001)).

A very large sample (662 different rate histories between 1993-2004) is analysed in Fuertes and Heffernan (2009) in a linear framework, again finding that there are considerable differences in pass-through and re-adjustment speed between banks. They also link this heterogeneity to other bank-specific variables that capture performance, and find that limited branch networks and managerial accountability to shareholders have a positive effect on adjustment speed.

In contrast to all previous work, I focus on the impact of the post-crisis disruption on economy-wide links between policy and money market rates, and retail mortgage rates, which are themselves important determinants of household income flows and generally acknowledged to provide an important monetary policy channel (see Britton and Whitley (1997)). I analyse 17 pair-wise relationships between money market and retail mortgage rates of the same maturity using aggregate monthly data from the Bank of England database for the period from January 1995 to May 2009. In the long-run I find evidence of a contrast between the discounted mortgage rates that banks use to initially attract customers, and standard variable-rates, with pass-through complete for the former but not for the latter. For fixed rate mortgages, pass-through is generally complete. Since the crisis, for eight of the estimated relationships I find strong evidence in the long-run of both a significant jump in equilibrium spreads, and a fall in pass-through, whilst in the short-run there is a considerable weakening of the process that re-adjusts retail rates back towards their equilibrium with the money market. Although I do not find strong statistical evidence for an asymmetric re-adjustment process before August 2007, retail mortgage rates generally take considerably longer to move back towards their equilibrium with wholesale rates during times when they are relatively expensive. These results add to previous studies by showing the extent to which the UK retail banking sector is imperfectly competitive at the aggregate level, and also suggest that discounted rates are used as a highly competitive loss-leader product. The following section describes the methodology, followed by analytical results in section 3, and section 4 concludes.

2 Methodology

I closely follow the procedures of Liu et al. (2008), which draw on theoretical results derived by Phillips and Loretan (1991). Since interest rates are generally not found to behave significantly different from unit root processes, the P-L method starts with a long-run equation, as used in the familiar Engle-Granger procedure. Crucially however, the possibility of a more general process is allowed for with the following triangular system of long-run equations:

$$r_t = \alpha_0 + \alpha_1 i_t + \varepsilon_{1t} \tag{1}$$

$$i_t = i_{t-1} + \varepsilon_{2t}, \tag{2}$$

where α_0 is the long-run mark-up of retail over wholesale rates and a_1 captures the proportion of (unexpected) changes in wholesale rates that eventually 'slip' or pass-through to retail rates. Pass-through is said to be complete when a_1 is not significantly different from 1, whilst $\alpha_1 < 1$ suggests an imperfectly competitive financial sector. If ε_{1t} is stationary, this implies cointegrated interest rates, so that direct OLS estimates of the parameters are super-consistent, although standard inference has to be adjusted for the non-standard parameter distributions. An often overlooked problem though, is that *a priori* it is reasonably likely that ε_{1t} and ε_{2t} are correlated, because retail bank profitability may depend on anticipating future expected changes in wholesale rates, especially if there are costs associated with adjusting rates. Appendix F provides a conceptual model of forward-looking rate-setting which would cause such a correlation.

The P-L method is hence a happy medium between an unrestricted VAR-type model whose coefficients are difficult to interpret, and the Engle-Granger estimates which are super-consistent, but likely to suffer from small sample bias and non-standard asymptotic parameter distributions. More specifically, the P-L method adds lagged error correction terms to counteract autocorrelation of ε_{1t}, and present, past and future first differences of i_t, to remove the effect of correlation between ε_{1t} and ε_{2t}. At the same time, past policy surprises, and future policy settings are accounted for, and the framework provides a simple way of testing for structural breaks. The long run (P-L) parameters with their associated shifts at the beginning of the crisis period, are derived by non-linear least squares estimation of the following equation:

$$r_t = \alpha_0 + \alpha_1 i_t + \alpha_2 D + \alpha_3 D i_t + \sum_{k=1}^{K} \theta_k \varepsilon_{t-k} + \sum_{i=-l}^{L} \mu_i \Delta i_{t-i} + v_t, \tag{3}$$

where D is a dummy variable equal to zero before the crisis period, and one thereafter; and ε_t is the disequilibrium of the long-run relationship calculated from $r_t - \alpha_0 - \alpha_1 i_t - \alpha_2 D - \alpha_3 D i_t$. The parameters α_2 and a_3 capture any long-run mark-up and pass-through shifts that occurred at the start of the crisis period. After establishing the long-run relationships, we can then focus on the short-run dynamics that govern the way rates re-equilibrate. I estimate the SEECM with retail rates as the dependant, endogenous variable:

$$\Delta r_t = \beta_0 \Delta i_t + \beta_{00} D \Delta i_t + \delta \widehat{\varepsilon}_{t-1} + \sum_{i=1}^{x} \beta_i \Delta i_{t-i} + \sum_{i=1}^{y} \gamma_i \Delta r_{t-i} + v_t, \tag{4}$$

where β_0 and $\beta_0 + \beta_{00}$ capture how much of a change in wholesale rates instantaneously passes through to retail rates before and after the crisis respectively. The error correction parameter δ indicates the strength of the re-adjustment mechanism, whilst the lagged differences of retail and wholesale rates capture all other short-run dynamics.

After establishing how parameters shifted after the crisis, I then follow Liu et al. (2008) again by searching for asymmetry of the re-adjustment mechanism. This is achieved by running a similar short-run equation, but with a dummy variable λ, equal to 1 when mortgage rates are above their equilibrium level, that is when the lagged disequilibrium term is positive, and zero when they are below equilibrium:

$$\Delta r_t = \beta_0 \Delta i_t + \beta_{00} \Delta i_t + \delta_1 \lambda \widehat{\varepsilon}_{t-1} + \delta_2 (1 - \lambda) \widehat{\varepsilon}_{t-1} + \sum_{i=1}^{x} \beta_i \Delta i_{t-i} + \sum_{i=1}^{y} \gamma_i \Delta r_{t-i} + v_t. \tag{5}$$

I am hence able to investigate whether or not the mechanism that moves retail mortgage rates towards their equilibrium with wholesale rates on impact, is stronger or weaker, depending on whether retail rates have (temporarily) moved above or below their equilibrium position relative to wholesale rates.

The linear error correction process provides a simple, parsimonious way of documenting the effects of the relatively small sample of observations from the post-crisis period. However, no allowance is made for the possibility of time-varying parameters and volatility. Plots of the disequilibrium terms, together with a reflection on the series of events during the financial crisis suggest there may have been increases in volatility, and perhaps a weakening of the process that re-adjusts rates towards their (new) equilibrium. In all cases the post-crisis period was associated only with *positive* disequilibria. A non-linear error correction process, driven by variables that reflect the new mortgage market risk premia of the period (perhaps related to unemployment and house price forecasts) may more closely describe the true underlying data-generating process. At the same time, with so many new events, and not a very long run of observations, I did not consider it worth applying any of the growing number of non-linear specifications in the literature [1]. Instead, the asymmetric analysis is restricted to the more reliable and consistent pre-crisis period. Evidence for asymmetry can be revealed by testing the null hypothesis that $\delta_2 = \delta_3$ with a standard parameter restriction Wald test. Additionally, given potentially low power for this test, a comparison of the short-run adjustment processes is made by comparing what Hendry (1995) refers to as the Mean Adjustment Lag (MAL) of the two different (above and below equilibrium) regimes. It works by treating the estimated relationship as if it were deterministic. Once stripped down into levels, the MAL is a weighted average of all the lags of the underlying processes, in this case capturing the average length of time it takes retail rates to respond to movements in wholesale rates. Appendix E provides a full description of how Hendry's formula is applied in this study.

Although many previous studies outlined in the introduction have searched for and found asymmetry in this context, none have done so at an aggregate level for the UK, nor specifically looked at how the setting of Discounted Variable Rate (DVR) differs from Standard Variable Rate Mortgages (SVR). I follow previous studies which interpret relatively long re-adjustment times for above-equilibrium regimes as indicative of imperfectly competitive bank behaviour. To the extent that the financial sector as a whole is slower to shift rates when they are uncompetitively priced at high levels, this is consistent with the collusive oligopoly and exploitation of consumer inertia arguments proposed in the literature. I am able to more carefully scrutinise this latter claim in particular, since after the two-year period during which DVRs are discounted (and re-set each period), they automatically revert back to SVRs. Evidence outlined in Callaghan et al. (2007) and elsewhere suggests that many borrowers do face significant problems obtaining the time, information, and psychological energy required for continuously searching and re-mortgaging towards the most competitive financial products. Given also that complex penalties, risks, and both financial and subliminal loyalties may be built in to contracts, DVRs could plausibly be used to entice borrowers, in much the same way that many businesses use 'loss-leaders' to physically draw customers into their selling-environment. I therefore interpret more uncompetitive behaviour in the setting of SVRs compared to DVRs as supportive evidence for these features, whilst documenting their extent during the pre-crisis period from January 1995 to August 2007.

[1] The bilinear model proposed by Peel and Davidson (1998) may be appropriate, given that during the crisis it is likely that risk-premia would not be constant. For applications of non-linear models see Fuertes et al. (2006) and Fuertes et al. (2008).

Table 1: Data Summary		
Rate	**Description**	**Code**
Short Rates		
DVR	Discounted Variable Mortgage Rate	IUMBV48
SVR	Standard Variable Mortgage Rate	IUMTLMV
P1	Official Policy Rate	IUMBEDR
G1	Government Bond Rate	1
LIBOR	Interbank Rate (3 month)	IUMAMIJ
B1	Interbank Rate (2 month)	1
Long Rates		
F2	Fixed Mortgage Rate (2 year)	IUMBV34
F3	Fixed Mortgage Rate (3 year)	IUMBV37
F5	Fixed Mortgage Rate (5 year)	IUMBV42
F10	Fixed Mortgage Rate (10 year)	IUMBV45
G2	Government Bond Rate (2 year)	1
G3	Government Bond Rate (3 year)	1
G5	Government Bond Rate (5 year)	1
G10	Government Bond Rate (10 year)	1
B2	Interbank Rate (2 year)	1
B3	Interbank Rate (3 year)	1
B5	Interbank Rate (5 year)	1
B10	Interbank Rate (10 year)	1
C10	Corporate Bond Rate (10-15 year)	2

1. Extracted from the Bank of England commercial bank and government liability yield curves provided on the financial market data section of their website.
2. 'UK Corporate Bond Yield' taken from Thomson Datastream based on the Sterling Aggregate Index compiled by Lehman Brothers

Figure 2:

3 Data and Analysis

I use monthly data provided on the Bank of England website for 18 different interest rate series containing 173 observations from January 1995 to May 2009, plus one series of corporate bond rates from Thomson Datastream. All series are complete except for the DVRs, which only became available from April 1998 (and which therefore contain 134 observations). The whole series covers a timespan of more than 14 years, including more than 3 years of the post-crisis period. Table 1 provides a summary of the variables.

Since DVRs and SVRs are re-priced by banks each month, the analysis compares them with short wholesale rates, including the average official policy rate, and short gilt and interbank yields. For fixed mortgage rates, I compare their behaviour to gilt and commercial interbank lending rates of the same maturity. Whilst the structure of such yields are not directly comparable to a mortgage that is nominally fixed for a period, before reverting to a standard variable-rate, these analyses offer a guide to the cost of funding such mortgages from wholesale money markets.

It is postulated here that by capturing elements of the term structure contained over the same time horizon, any differences in the dynamic behaviour of retail rates are more likely to reflect imperfections in the financial sector. To the extent that the appropriate expectations of inflation and risk premia over the same time horizon are captured and thus conditioned, this analysis sheds light on financial sector frictions, rather than term structure features.

3.1 Equilibrium Relationships

I follow Liu et al. (2008) in drawing on the theoretical results of Phillips and Loretan (1991) to derive the long-run equilibria between wholesale money market and retail mortgage rates. First of all, I check the two assumptions that have usually been found in the literature, that the underlying interest rates behave in a non-stationary (unit-root) way, and that they cointegrate in the long-run. Appendix A shows time-series plots of all 17 pairs of interest rates, with their associated spreads. In all cases there is clearly a very strong degree of co-movement, and a maintained economic assumption of this paper is that there is a firm long-run relationship between retail mortgage rates and the associated money market rates that financial institutions borrow and lend at. Even when there are imperfections in the banking sector, it is hard to imagine rates wandering away for too long, and competitive forces not eventually intervening to restore some kind of equilibrium. The results and a summary of the formal stationarity and cointegration tests are presented in appendices B and C. Without emphatic evidence that the interest rates cannot be treated as non-stationary, and that their relationships cannot be treated as cointegrated, I again follow Liu et al. (2008) by proceeding with the P-L method. It can be argued that the imposition of discete values for orders of integration may be unrealistic anyway, in which case there are obviously problems with these tests. Beechey et al. (2009) for example develops procedures for testing interest rates when they are *near* integrated, implying that the cointegrating vector is not equal to the usually assumed discrete values $[1, -1]$. Fuertes and Heffernan (2009) also discusses the issue of comovement and cointegration, which we do not explore further here.

Phillips and Loretan (1991) showed how asymptotically median unbiased and efficient estimators could be derived with a range of equivalent methods, namely full systems maximum likelihood; fully modified OLS; systems estimation in the frequency domain; single-equation band spectral estimation; and finally non-linear ECM estimation. Their study systematically analysed the latter method, and stressed the importance of including *leads* of first differences of the regressors in single-equation ECMs (SEECMs). Without such augmentation, the efficiency, unbiasedness, and retention of standard properties for valid inference fail. At the same time they also showed that, given non-stationarity of the underlying (cointegrated) processes, lagged first differences of the variables (in our case lags of Δr_t and Δi_t) did not adequately remove the effects of the past history of errors on the long-run relationship (in our case ε_{1t}). Whilst OLS on linear SEECMs with differenced lags of both variables would be computationally simpler, a non-linear least squares (NLS) procedure is necessary. To estimate the long-run equations (3), (4), and (5) presented in section 2, I also follow their prescription of NLS estimation applied to the non-linear-in-parameters equations that include lagged disequilibrium terms.

Given the structure and assumptions of Phillips and Loretan (1991), the P-L estimator has asymptotic equivalence with the more popular (full systems maximum liklihood) Johansen procedure, but with the added benefit that we can more easily interpret its natural endogenous-exogenous structure. The next practical problem we face is that of choosing the number of lags and leads to include in the equations presented in section 2. Although other work at the time (see Saikkonen (1991) and Stock and Watson (1993)) developed the asymptotic theory of regressions with leads and lags, only more recently have practical procedures been devised for their selection. In the context of lag selection for unit-root testing, Ng and Perron (1995) explores how to trade-off between parsimonious models with size distortions and over-parameterised models which suffer from low power. They showed that general-to-specific procedures with sequential t- and f-tests outperformed the minimisation of information criteria. For cointagrated models with *leads* however, Kejriwal and Perron (2008) have extended the analysis of Saikkonen (1991) and found the opposite: Akaike and Bayesian information criteria (AIC and BIC) can be validly used for the leads and lags regression (which they refer to as 'dynamic OLS') under slightly weaker assumptions; and simulations find smaller mean squared errors and better coverage rates for confidence intervals. Choi and Kurozumi (2008) also includes analysis of the less well known Cp criterion which minimises the expected squared sum of forecast errors (see Mallows (2000)). Their simulations show that a simplified approximation of this criterion is the best at reducing bias, whilst BIC is the most successful at reducing mean squared errors. In this study I use the Cp criterion, but also undertake a sensitivity analysis using AIC and BIC (for a description of how these criteria are applied see Appendix D). The following 2 sections summarise the estimation results for the 17 pair-wise relationships analysed between variable-rate mortgages and short money market yields, and between fixed rate mortgages and money market yields fixed for the same maturity.

3.1.1 Variable Mortgage Rates and Short Yields

Table 1 presents the estimated long-run relationships between SVRs and wholesale rates. The slope coefficients under the second column show that SVRs are most strongly linked to gilt yields, with 87% of adjustments passing through to SVRs. For interbank rates there is 80% pass-through, whilst only 77% of changes in the policy rate are fully reflected by SVRs in the long-run. Generally speaking, we can say that the way banks set SVRs is not very closely tied to conditions in wholesale markets, with column 7 showing that there is strong evidence in the data to reject the null of complete pass-through.

This contrasts strongly with the long-run relationships for DVRs observed since April 1998, presented in Table 2. Between 93% and 103% of adjustments to wholesale rates are eventually fully reflected in DVRs, and there is no strong evidence to reject the proposition that in the long-run, there is a one-to-one link from policy, gilt, and interbank yields through to DVRs. Compared to SVRs this suggests that banks set DVRs in a more efficient and competitive way.

Another contrasting feature between tables 1 and 2 is the estimated level of equilibrium spreads. Whilst the equilibrium wholesale mark-up for SVRs is around 2.5 percentage points (and 285bps above policy rate), the cost of DVRs is insignificantly different from any of the interbank, government and policy rates.

Moving to the post-crisis period, column 4 shows that the pass-through from policy to SVRs fell significantly (by 6 percentage points down to 71%). In the long-run, the evidence for a long-term break in the link between wholesale and mortgage rates was strongest for DVRs and LIBOR. Pass-through fell by 10 percentage points, and the null of complete pass-through was rejected post-crisis, but not pre-crisis.

There were also significant shifts in the long-run mark-up from policy to SVRs (up 380bps), and even larger jumps in the spreads from gilt and interbank rates to DVRs (up 550 and 570bps). To the extent that the DVR mortgage market is more competitive, this latter result could be interpreted as reflecting increases in mortgage market risk premia caused by mortgage-specific factors such as worsening unemployment and house-price forecasts.

Table 1: Long Run Pass Through to Standard Variable Mortgage Rates

Short Rate	Pre-Crisis		Post-Crisis Effect		R^2	DW	Ho: Complete Pass Through	
	Constant	Slope	Constant	Slope			Pre-Crisis	Post-Crisis
Policy	2.85^c	0.77^c	$+0.38^c$	-0.06^c	1.00	2.02	0.000	0.000
	(8.3)	(12.1)	(5.3)	(-4.8)				
T-Bill	2.42^c	0.87^c	+0.18	-0.02	0.99	1.96	0.007	0.002
(3-month)	(9.5)	(17.8)	(p=0.105)	(p=0.357)				
LIBOR	2.61^c	0.80^c	-0.25	+0.03	0.99	1.97	0.000	0.005
(3-month)	(8.8)	(14.8)	(p=0.219)	(p=0.339)				
Interbank	2.55^c	0.80^c	-0.17	+0.02	0.99	2.00	0.000	0.002
(2-month)	(8.7)	(15.2)	(p=0.245)	(p=0.338)				

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. P-values for a Chi-Squared Test with Slope Coefficient restricted=1 (small value indicates evidence for incomplete pass through)
Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

Figure 3:

3.1.2 Fixed Mortgage Rates and Long Yields

The long-run links between fixed mortgage rates, and gilt, interbank, and corporate bond yields of the same maturity are shown in tables 3 and 4. In all cases, the links are very tight, with pass-through ranging from 95% to 105% (except from corporate bonds with 92% pass-through), and no rejections of the complete pass-through hypothesis other than from 3-year gilts to 3-year fixed-rates. Another characteristic that indicates a competitive fixed-rate mortgage market is the fairly tight long-run spreads, which for the interbank rates are insignificantly different from zero in all cases except for at 3-year maturities. Equilibrium spreads over gilts range from 0.61 percentage points for 2-year rates, up to 1 percentage point for 3-year maturities, in all cases significantly cheaper than the SVR spreads. At this point it is worth pointing out that, just as DVRs revert back to SVRs after the pre-agreed 2-year period, so do fixed-rates revert back to SVRs at maturity. The fixed-rate mortgage market appears to be more competitive than SVRs,

Table 2: Long Run Pass Through to Discounted Variable Mortgage Rates

Short Rate	Pre-Crisis		Post-Crisis Effect		R^2	DW	Ho: Complete Pass Through	
	Constant	Slope	Constant	Slope			Pre-Crisis	Post-Crisis
Policy	0.41	0.93^c	$+0.60^a$	-0.09	0.97	2.02	0.478	0.072
	(p=0.399)	(9.5)	(2.4)	(p=0.057)				
T-Bill	0.04	1.03^c	$+0.55^b$	-0.08^a	0.99	2.05	0.724	0.478
(3-month)	(p=0.918)	(12.7)	(3.07)	(-2.4)				
LIBOR	0.31	0.93^c	$+0.57^b$	-0.10^b	0.99	2.04	0.174	0.001
(3-month)	(p=0.206)	(19.3)	(3.0)	-2.9				
Interbank	0.15	0.96^c	$+0.35^a$	-0.06	0.99	2.06	0.540	0.117
(2-month)	(p=0.653)	(14.6)	(2.1)	(p=0.071)				

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. P-values for a Chi-Squared Test with Slope Coefficient restricted =1 (small value indicates evidence for incomplete pass through)
Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

Figure 4:

and again this is consistent with the idea that banks use fixed-rates (though to a lesser extent than DVRs) as loss-leader products to entice borrowers into deals which later become less competitive.

After the crisis, the fall in pass-through and rise in equilibrium spread is even more clear-cut: For all but the 10-year fixed-rates link with 10-year gilts, there was both a significant reduction in pass-through (from 6 to 14 percentage points), and increase in equilibrium spreads (from 44 to 80 percentage points). Another feature of the crisis period is that, for 3-year interbank rates, the hypothesis of complete pass-through to fixed-rates is rejected (but not before the crisis).

3.2 Short Run Adjustment

To estimate the short-run equation 4, the number of differenced lags of the exogenous (x) and endogenous (y) variable were selected with Bayesian information criteria (BIC). Using a maximum lag-length of 4, I optimised BIC across all possible combinations of x and y, to derive the chosen $SR(x, y)$ models whose results are presented in tables 5-8. The first and fourth columns of these tables give the values of β_0 and β_{00} from equation 4, the proportion of a change in wholesale rates that instantaneously slips through to retail rates before the crisis, and the change in this parameter after the crisis. The re-adjustment coefficient δ is shown in columns 2 and 5 (before the crisis, and the change after the crisis respectively), and indicates the strength of the re-adjustment process towards equilibrium (the proportion of a disequilibrium that is immediately 'corrected'). We would normally expect this parameter to be negative, given that there is a long-term equilibrium, since positive values imply an error-exploding, rather than self-correcting process. Finally, columns 3 and 6 show the results of calculating the Mean Adjustment Lag (MAL), before and after the crisis (see Appendix E). The MAL is an average measure of how long it takes for a disequilibrium between wholesale and retail rates to disappear. Since there are both error-correction terms and differenced lags in the final models, this calculation is important

Table 3: Long Run Pass Through from Government Bonds to Fixed Mortgage Rates

Maturity	Pre-Crisis[1]		Post-Crisis Effect		R^2	DW	Ho: Complete Pass Through[2]	
	Constant	Slope	Constant	Slope			Pre-Crisis	Whole-Sample
Two Year	0.61[a]	0.98[c]	+0.60[c]	-0.08[c]	0.98	2.00	0.674	0.034
	(2.4)	(20.8)	(4.1)	(-2.7)				
Three Year	1.00[c]	0.95[c]	+0.53[c]	-0.07[a]	0.98	1.98	0.039	0.000
	(4.9)	(25.4)	(3.5)	(-2.2)				
Five Year	0.64[a]	1.04[c]	+0.50[c]	-0.08[a]	0.99	2.02	0.428	0.359
	(2.5)	(22.4)	(3.3)	(-2.6)				
Ten Year	1.20[b]	0.98[c]	+0.39	-0.08	0.99	2.03	0.849	0.323
	(2.7)	(12.4)	(p=0.178)	(p=0.231)				

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. P-values for a Chi-Squared Test with Slope Coefficient restricted=1 (small value indicates evidence for incomplete pass through)
Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

Figure 5:

Table 4: Long Run Pass Through from Interbank Loan Rates to Fixed Mortgage Rates

Maturity	Pre-Crisis[1]		Post-Crisis Effect		R^2	DW	Ho: Complete Pass Through[2]	
	Constant	Slope	Constant	Slope			Pre-Crisis	Post-Crisis
Two Year	0.35[b]	0.96[c]	+0.44[b]	-0.06[a]	0.98	1.99	0.518	0.052
	(p=0.272)	(17.6.)	(4.7)	(-3.6)				
Three Year	0.60[a]	0.95[c]	+0.48[b]	-0.07[a]	0.99	2.00	0.291	0.007
	(2.3)	(21.2)	(3.0)	(-2.5)				
Five Year	0.18	1.04[c]	+0.64[c]	-0.10[c]	0.99	1.97	0.333	0.121
	(p=0.414)	(27.2)	(4.0)	(-3.4)				
Ten Year	0.37	1.05[c]	+0.80[b]	-0.14[a]	0.99	2.01	0.313	0.175
	(p=0.228)	(20.6)	(2.8)	(-2.5)				
Ten Year	0.58	0.92[c]	+0.65[a]	-0.11[b]	0.99	2.02	0.587	0.158
(Corporate)	(p=0.51)	(6.7)	(2.4)	(-2.8)				

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. P-values for a Chi-Squared Test with Slope Coefficient restricted=1 (small value indicates evidence for incomplete pass through)
Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

Figure 6:

in clarifying the general speed of the short-term adjustment of retail rates following changes in wholesale rates.

3.2.1 Variable Mortgage Rates and Short Yields

Table 5 shows the estimated short-run relationships for SVRs and DVRs respectively. The instantaneous re-adjustment in column 2 is considerably stronger in all cases for DVRs compared to SVRs, indicative of more competitive behaviour. Immediate pass-through was not significant for interbank rates, but again the larger values for DVRs with respect to policy and gilt yields suggest a more immediately competitive DVR-setting process than for SVRs. The MALs on the other hand are longer for DVRs in all cases. This suggests that early on, banks are quicker to pass on the rate changes to DVRs, but then it takes longer on average for the whole change to be reflected in DVRs. Columns 4-6 show how short-run adjustment changed after the crisis. In all cases, the change in instantaneous pass-through was insignificant, and all re-adjustment parameters became weaker (less negative). Caution is required in interpreting the MALs, where they are based on a relatively small number of observations (and in some cases were negative with no meaningful interpretation). Generally speaking, MALs are much longer in the post-crisis period, which probably illustrates a looser link between wholesale and retail rates after the crisis.

Table 5: Short Run Pass Through to Variable Mortgage Rates

Short Rate	Pre-Crisis[1]			Post-Crisis[1]		
	Impact		MAL[4]	Impact		MAL[4]
	Pass Through[2]	Re-Adjustment[3]		Pass Through[2]	Re-Adjustment[3]	
SVR						
Policy	0.18^{c}	-0.09^{c}	0.8	-0.08	$+0.15^{b}$	1.9
	(4.0)	(-3.5)		(p=0.183)	(2.7)	
T-Bill	0.12^{b}	-0.14^{c}	3.3	-0.09	$+0.08^{c}$	4.9
(3-month)	(2.6)	(3.7)		(p=0.221)	(2.0)	
LIBOR	0.08	-0.17^{c}	2.8	+0.06	$+0.22^{a}$	-
(3-month)	(p=0.217)	(-4.6)		(p=0.395)	(2.4)	
Interbank	0.01	-0.13^{c}	4.8	+0.07	+0.03	2.9
(2-month)	(p=0.868)	(-3.5)		(p=0.322)	(p=0.602)	
DVR						
Policy	0.60^{c}	-0.19^{b}	3.0	-0.15	$+0.20^{b}$	-
	(6.7)	(-3.2)		(p=0.146)	(-3.2)	
T-Bill	0.33^{c}	-0.20^{b}	3.7	-0.14	$+0.18^{a}$	22.7
(3-month)	(4.0)	(-3.1)		(p=0.149)	(2.6)	
LIBOR	0.40^{c}	-0.29^{c}	4.0	-0.03	$+0.21^{c}$	7.7
(3-month)	(4.9)	(-5.7)		(p=0.729)	(3.3)	
Interbank	-0.12	-0.27^{c}	5.3	+0.14	$+0.18^{c}$	7.9
(2-month)	(p=0.151)	(-7.0)		(p=0.157)	(4.3)	

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. Impact pass through indicates how much of a change in wholesale rates is immediately passed through to retail rates.
3. Impact Re-Adjustment is the size of the equilibrium correction parameter.
4. Mean Adjustment Lags, which indicate how long it takes retail rates to adjust to changes in wholesale rates (see appendix E).
5. Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

3.2.2 Fixed Mortgage Rates and Long Yields

The re-adjustment parameters in Table 6 suggest that the fixed-rate mortgage market link to treasury bill, as opposed to interbank lending, is slightly stronger. Re-adjustment parameters are slightly stronger for gilts at all maturities, and MALs slightly shorter at 3, 5, and 10-year maturities. As for short rates, the post-crisis changes cannot be measured with accuracy, however in all cases there was a significant weakening of the re-adjustment process.

Table 6: Short Run Pass Through to Fixed Mortgage Rates

Maturity	Pre-Crisis[1]			Post-Crisis[1]		
	Impact		MAL[4]	Impact		MAL[4]
	Pass Through[2]	Re-Adjustment[3]		Pass Through[2]	Re-Adjustment[3]	
T-Bill						
Two Year	0.10	-0.24^{c}	4.4	+0.10	0.22^{c}	17.7
	(p=0.051)	(-5.4)		(p=0.315)	(4.6)	
Three Year	0.09	-0.27^{c}	4.0	+0.13	+0.23^{c}	10.2
	(p=0.061)	(-5.7)		(p=0.183)	(4.5)	
Five Year	0.15^{c}	-0.17^{c}	4.6	+0.14	+0.19^{c}	-
	(3.7)	(-4.7)		(p=0.109)	(4.6)	
Ten Year	0.17^{b}	-0.14^{c}	5.1	-0.03	+0.05	4.6
	(3.0)	(-4.7)		(p=0.819)	(p=0.499)	
Interbank						
Two Year	0.13^{b}	-0.23^{c}	4.3	+0.21	+0.24	-
	(2.7)	(-5.6)		(2.4)	(4.7)	
Three Year	0.12^{b}	-0.22^{c}	4.4	+0.04	+0.17^{c}	9.1
	(2.4)	(-4.8)		(p=0.687)	(3.3)	
Five Year	0.18^{c}	-0.17^{c}	4.5	+0.06	+0.18^{c}	-
	(4.4)	(-4.9)		(p=0.498)	(4.2)	
Ten Year	0.18^{b}	-0.10^{c}	6.1	+0.07	+0.12^{b}	-
	(3.0)	(-3.4)		(p=0.597)	(2.6)	
Ten Year (Corporate)	0.05	-0.10^{c}	11.4	-0.05	+0.11^{c}	-
	(p=0.502)	(-4.6)		(p=0.652)	(4.1)	

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. Impact pass through indicates how much of a change in wholesale rates is immediately passed through to retail rates.
3. Impact Re-Adjustment is the size of the equilibrium correction parameter.
4. Mean Adjustment Lags, which indicate how long it takes retail rates to adjust to changes in wholesale rates (see appendix E).
5. Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

3.3 Asymmetric Adjustment

Now we turn to the question of whether bank rate-setting behaviour varies according to whether retail rates are above or below their long-term equilibrium with wholesale rates. Some of the literature discussed in the introduction links oligopolistic competition between banks, and other inertia to asymmetric adjustment of rates. Such imperfections may mean that banks are relatively slow to re-adjust during 'expensive' (above equilibrium) periods than during the 'cheap' (below equilibrium) regimes. If so, then we interpret evidence for asymmetry as evidence for an imperfectly competitive financial sector. A time series plot of all rates is provided in Appendix A. In all cases except for the fixed-rate relationship with corporate bonds, the post-crisis period almost exclusively associated with *positive* disequilibria. We also know that this was a time when many events were unfolding. As discussed in previous sections, I do not relax equations 2, 4, and 5 to allow for time-varying error-correction (which is likely to have weakened), and volatility (which is likely to have increased). There are many possible candidate, non-linear models that could capture these features, but the limited observations may not warrant such an approach. For the asymmetry analysis in particular however, there is a clear danger that including the post-crisis period may distort the estimation, possibly biasing the above-equilibrium parameters upwards, as well as causing invalid inference. At the cost of less observations, I adopt a conservative approach by excluding the post-crisis sample from this analysis, thus avoiding the danger that we have not appropriately captured the changes after August 2007.

Table 7: Asymmetric Adjustment of Variable Mortgage Rates[1]

Short Rate	Impact			MAL[4]		Ho: Asymmetry[6]
	Pass Through[2]	Re-Adjustment[3] Above[5]	Re-Adjustment[3] Below[5]	Above[5]	Below[5]	
SVRs						
Policy	0.36^c (4.9)	-0.31^c (-5.0)	-0.23^c (-4.3)	1.6	-0.5	0.340
T-Bill (3-month)	0.11^a (2.4)	0.17^c (-3.5)	-0.12^a (-2.6)	3.1	1.5	0.171
LIBOR (3-month)	0.16^b (2.7)	-0.17^c (-3.4)	-0.09 (p=0.064)	2.7	1.4	0.178
Interbank (2-month)	0.20 (p=0.728)	-0.17^c (-3.5)	-0.11^a (-2.4)	4.2	3.6	0.142
DVRs						
Policy	0.49 (5.7)	-0.19^b (-2.6)	-0.13 (p=0.125)	2.8	1.2	0.576
T-Bill (3-month)	0.26^c (3.7)	-0.23^c (-5.4)	-0.30^c (-4.3)	4.6	3.0	0.319
LIBOR (3-month)	0.37^c (5.1)	-0.26^c (-4.7)	-0.23^c (-3.5)	3.7	3.4	0.713
Interbank (2-month)	-0.08 (p=0.255)	-0.30^c (-8.0)	-0.27^c (-5.1)	5.1	4.7	0.604

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007.
2. Impact pass through indicates how much of a change in wholesale rates is immediately passed through to retail rates.
3. Impact Re-Adjustment is the size of the equilibrium correction parameter.
4. Mean Adjustment Lags indicate how long it takes retail rates to adjust to changes in wholesale rates (see appendix E).
5. 'Above' and 'below' indicate regimes when deviation from long-run equilibrium is positive and negative respectively.
6. P-values for a Chi-Squared Test on the general restriction that the re-adjustment parameters for the two regimes are equal (small values indicate evidence of asymmetry).
7. Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

Figure 7:

The p-values given in the last column of Table 7 suggest that there is slightly stronger statistical evidence of asymmetry (and hence imperfect competition) for SVRs, although this evidence is not significant. The MALs shown in columns 4 and 5 however, suggest that banks take longer to re-adjust rates during above equilibrium regimes. Pass-through from both LIBOR and treasury bill rates to SVRs takes on average, twice as long when SVRs are relatively expensive, compared

Table 8: Asymmetric Adjustment of Fixed Mortgages[1]

Maturity	Impact			MAL[4]		Ho: Asymmetry[6]
	Pass Through[2]	Re-Adjustment[3] Above[5]	Re-Adjustment[3] Below[5]	Above[5]	Below[5]	
T-bills						
Two Year	0.10^{a}	-0.21^{c}	-0.25^{c}	4.4	2.0	0.616
	(2.0)	(-4.0)	(-3.3)			
Three Year	0.12^{a}	-0.12^{c}	-0.56^{c}	5.4	0.7	0.005
	(2.6)	(-3.5)	(-3.4)			
Five Year	0.14^{c}	-0.16^{c}	-0.21^{b}	4.9	2.3	0.454
	(3.6)	(-3.7)	(-3.2)			
Ten Year	0.15^{b}	-0.16^{c}	-0.19^{c}	5.5	5.9	0.625
	(2.7)	(-5.1)	(-3.3)			
Interbank						
Two Year	0.13^{a}	-0.19^{c}	-0.22^{b}	4.3	2.0	0.705
	(2.6)	(-3.9)	(3.0)			
Three Year	0.11^{a}	-0.22^{c}	-0.20^{b}	4.0	2.3	0.702
	(2.5)	(-4.0)	(-3.0)			
Five Year	0.20^{c}	-0.24^{c}	-2.1^{b}	4.0	2.4	0.538
	(5.1)	(-4.7)	(-3.2)			
Ten Year	0.19^{c}	-0.26^{c}	-0.24^{c}	4.9	3.1	0.817
	(3.3)	(-6.3)	(-4.2)			
Ten Year (corporate)	0.08	-0.09^{c}	-0.08	8.7	14.6	0.945
	(p=0.205)	(-3.9)	(p=0.060)			

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007.
2. Impact pass through indicates how much of a change in wholesale rates is immediately passed through to retail rates
3. Impact Re-Adjustment is the size of the equilibrium correction parameter
4. Mean Adjustment Lags indicate how long it takes retail rates to adjust to changes in wholesale rates (see appendix E)
5. 'Above' and 'below' indicate regimes when deviation from long-run equilibrium is positive and negative respectively.
6. P-values for a Chi-Squared Test on the general restriction that the re-adjustment parameters for the two regimes are equal (small values indicate evidence of asymmetry).
7. Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

Figure 8:

to when they are relatively cheap, which can be interpreted as evidence of imperfect competition.

A similar story is given for fixed-rate mortgages shown in table 8, although strong statistical evidence for asymmetry was found for the 3-year rate relationship with gilt yields. It takes nearly 8 times longer for 3-year fixed-rates to re-adjust when they are above equilibrium than when they are below.

4 Conclusion

In this paper I have investigated the dynamic relationships between a range of wholesale money markets, and comparable mortgage rates of the same maturity, to show how competitive forces differ between different types of mortgage product, and to see how much these relationships have been altered by the post-August 2007 financial market turmoil. I show the extent to which frictions (whether through a lack of competition or otherwise) prevent fully competitive rate-setting for three types of mortgage: discounted variable-rate mortgages (DVRs), standard variable-rate mortgages (SVRs), and fixed-rate mortgages (FRs). Across three types of dynamic analysis (long-run, short-run, and asymmetry) I find evidence that supports the hypothesis that banks may exploit consumer inertia by using DVRs, and to a lesser extent FRs, to entice borrowers in to 'cheap' deals that later may revert back to SVRs.

Firstly, using the P-L method to investigate long-run relationships I find that banks tend to pass rate changes fully on to DVRs, generally to FRs, but not to SVRs.

Secondly, the short-run dynamics show that banks tend not to pass any instantaneous changes onto SVRs, whereas they do for DVRs, and that the readjustment process is stronger in the latter case. On average however, it takes longer for rate changes to pass fully onto DVRs.

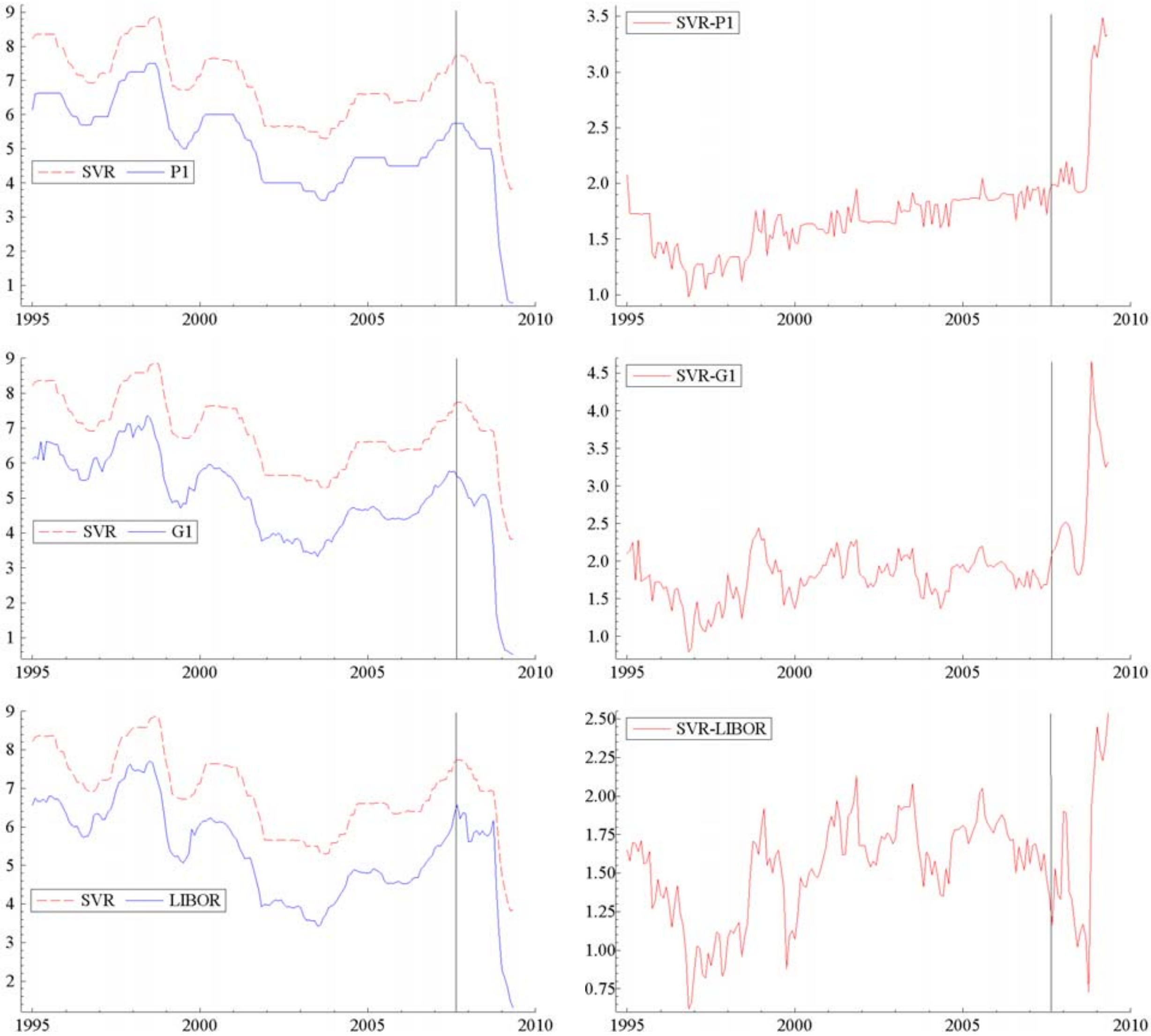
Finally, there is no strong statistical evidence that banks alter their rate-setting behaviour depending on whether retail mortgage rates are above or below their equilibrium with wholesale rates. It does however, take considerably longer for banks to re-adjust rates during above equilibrium regimes for SVRs, which again is indicative of imperfect competition in this market.

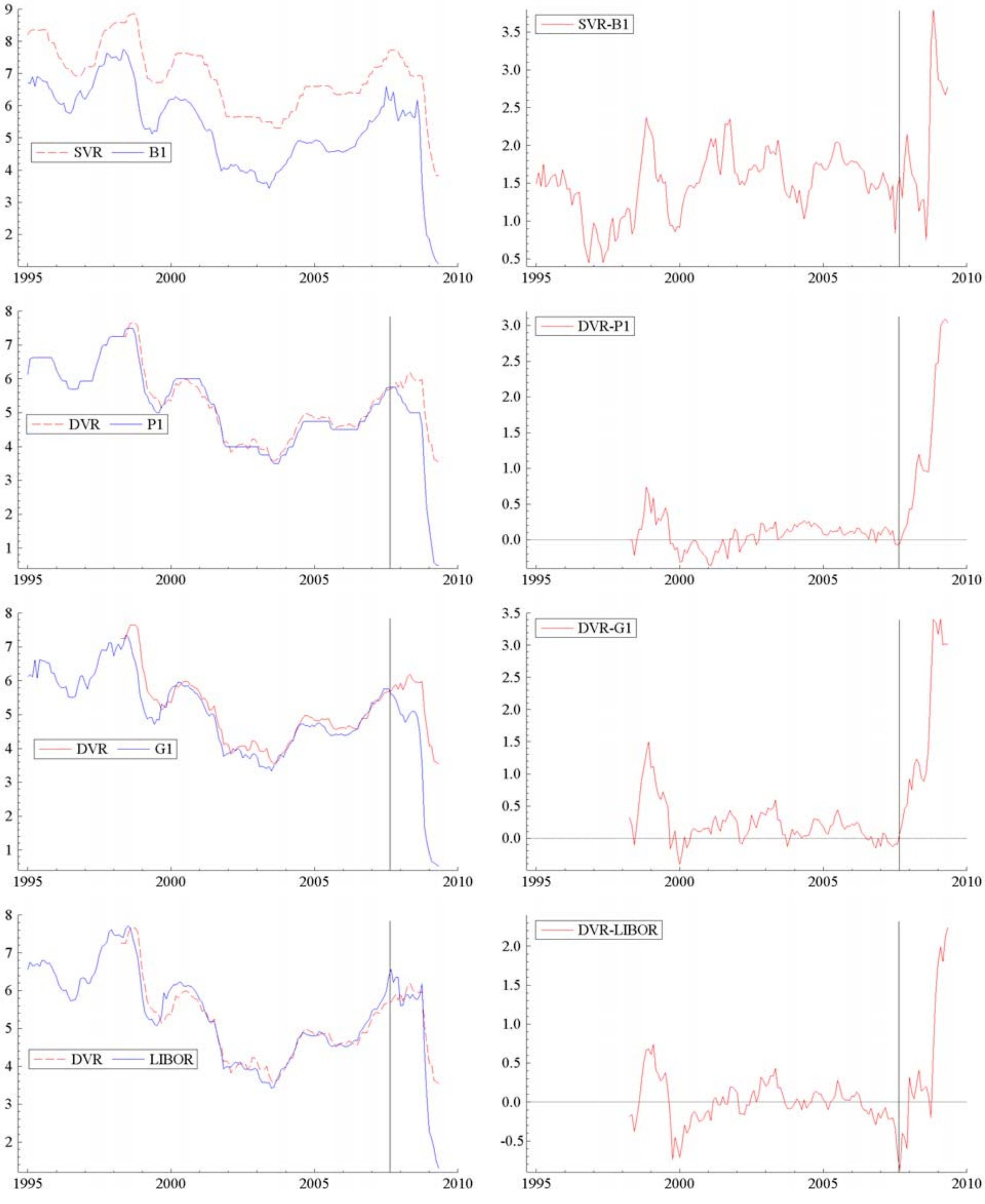
As for the post-crisis effect, there is strong evidence that both long-run and short-run relationships have been significantly altered. Since the crisis, for eight of the estimated relationships I find strong evidence in the long-run of both a significant jump in equilibrium spreads, and a fall in pass-through, whilst in the short-run there is a considerable weakening of the process that re-adjusts retail rates back towards their equilibrium with the money market.

For future work, given the complex chain of events since August 2007, the use of an *exogenous* time-varying error correction term, that depends on stress in the financial system may be appropriate. Different measures of financial stress could be tested against each other, to find which of them are the most successful at capturing the weakening of the error correction process. The candidates for such a variable need not be restricted to individual series. Illing and Liu (2006) for example, develop a way of compiling an index in Canada that captures stress in the financial system using a range of financial variables.

A Interest Rate Graphs

This appendix presents graphs of the 17 pairwise modelled relationships. For all graphs, the x-axis is time during the sample period from January 1995 to May 2009. For each pair, the graph on the left shows the interest rate levels throughout the sample period, and the graph on the right shows their difference (the interest rate spread). The line indicates the crisis period, August 2007. For a summary of variable abbreviations, see Table 1.




SVR
B1
SVR-B1
DVR
P1
DVR-P1
DVR
G1
DVR-G1
DVR
LIBOR
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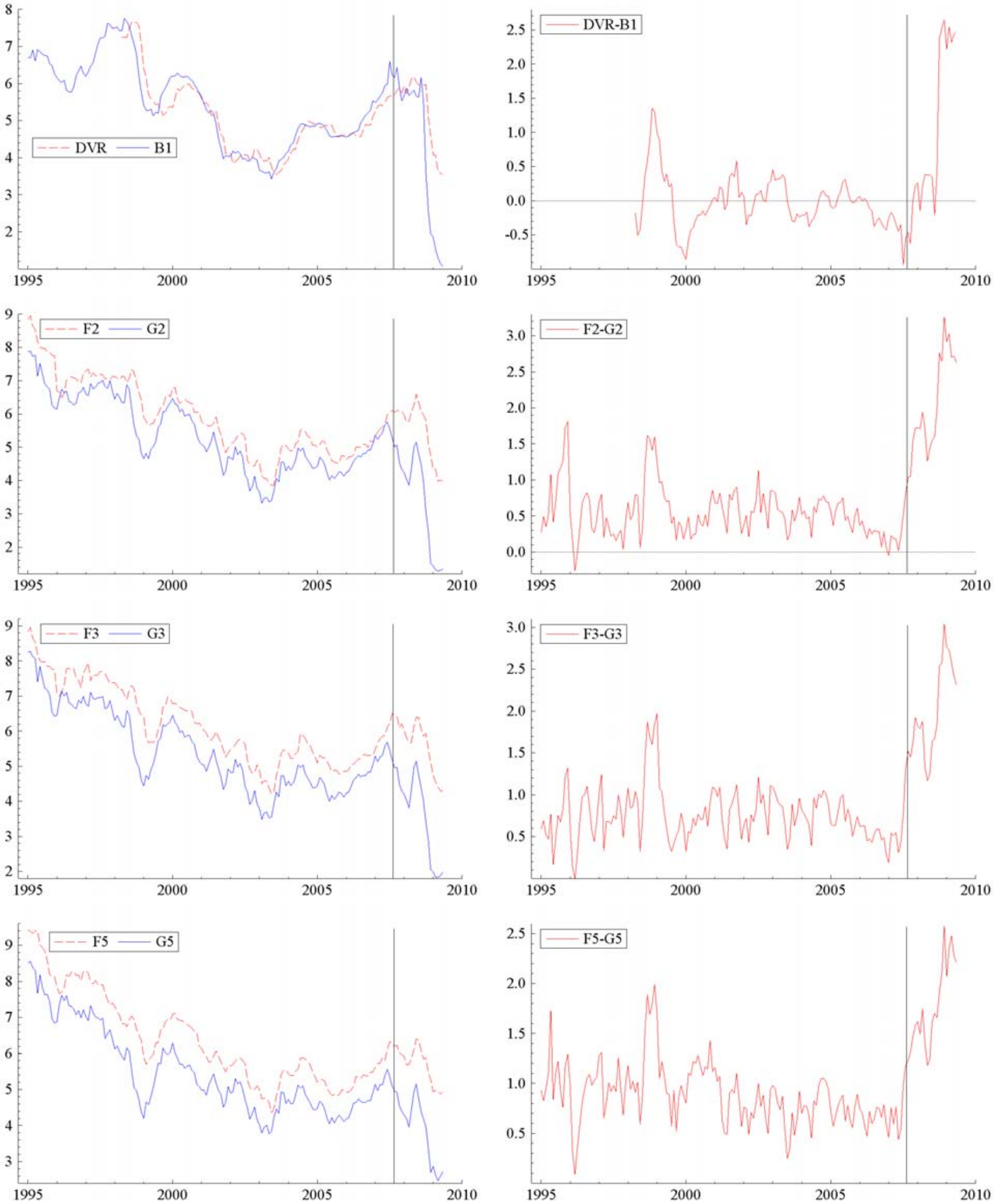
2000
2005
2010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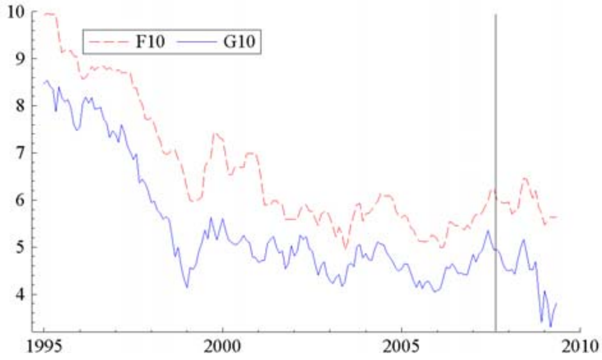
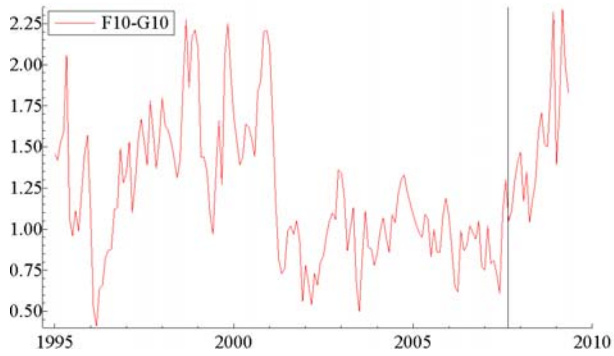
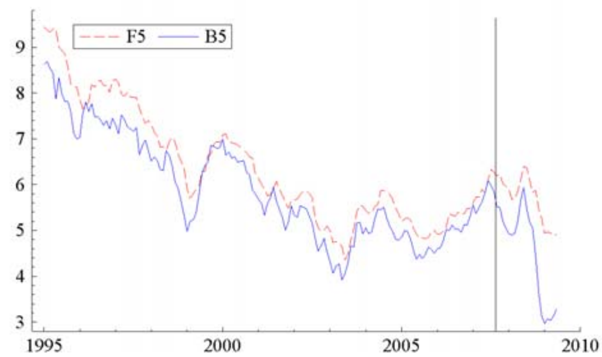
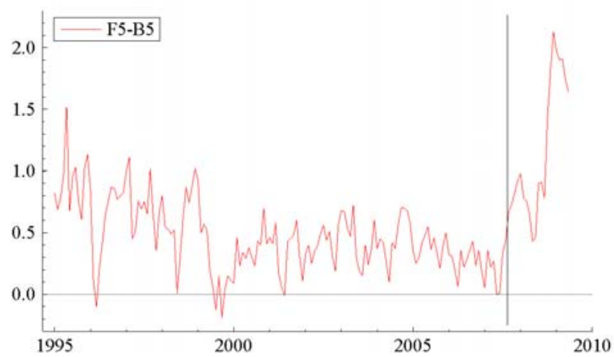
B1
DVR-B1
F2
G2
F2-G2
F3
G3
F3-G3
F5
G5
F5-G5


F10
G10


F10-G10


F5
B5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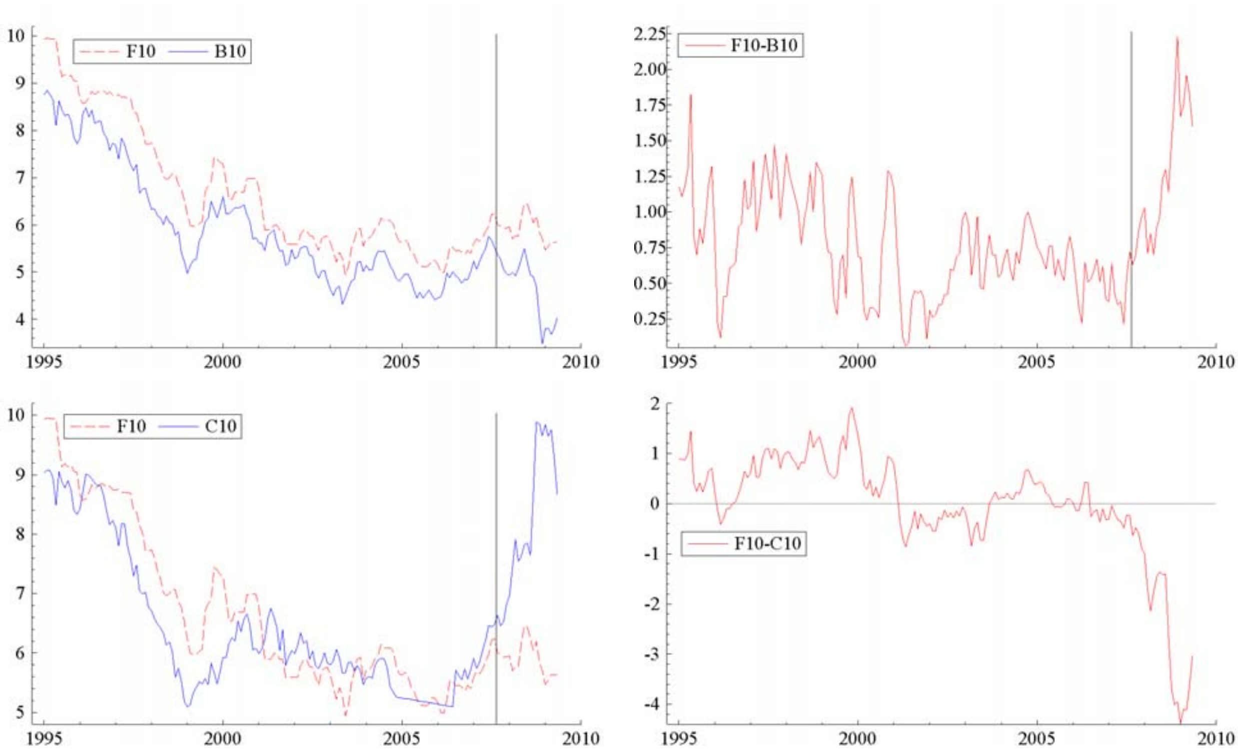

B Unit Root Tests

This appendix presents four tests, two of which assume the null hypothesis of a stationary, I(0) process (the KPSS and Lo's RS tests), and two assume the null of a unit-root, I(1) process (the ADF and P-P tests). The (unknown) assumptions about the true data-generating process vary according to test, and so ultimately does the (unknown) trade-off between low-power (under-rejection) and size-distortion (over-rejection), so the results should be treated only as indicative. Table B1 shows that there is no evidence across the whole sample to reject any of the tests, whilst table B2 shows that once a trend is allowed for, all KPSS tests for stationarity are firmly rejected, whilst 10 of the 17 Lo's RS tests are not rejected. None of the tests for non-stationarity are rejected. For the pre-crisis period, there is insufficient evidence to reject any of the tests, other than for the fixed mortgage rate de-trended data.

Table B1: Stationarity Tests on Underlying Data (Whole Sample)

Rate	Mean	S.D.	Ho: I(0) (stationary)		Ho: I(1) (non-stationary)	
			KPSS[1]	Lo's RS[2]	ADF[3]	P-P[4]
SVR	6.9	1.0	0.02 (<1)	0.27 (<1)	-2.2 (<0.9)	-1.0 (<0.9)
DVR	3.9	2.3	0.28 (<1)	1.06 (<0.8)	-2.1 (<0.9)	-2.2 (<0.9)
LIBOR	5.4	1.3	0.06 (<1)	0.43 (<1)	-1.1 (<0.9)	-0.7 (<0.9)
G1	5.0	1.3	0.08 (<1)	0.46 (<1)	-1.3 (<0.9)	-0.4 (<0.95)
P1	5.2	1.3	0.08 (<1)	0.47 (<1)	-1.3 (<0.9)	-0.1 (<0.95)
B1	5.3	1.3	0.07 (<1)	0.45 (<1)	-0.9 (<0.9)	-0.5 (<0.9)
F2	5.9	1.1	0.06 (<1)	0.40 (<1)	-2.3 (<0.9)	-2.2 (<0.9)
F3	6.1	1.1	0.06 (<1)	0.38 (<1)	-2.2 (<0.9)	-2.0 (<0.9)
F5	6.3	1.2	0.07 (<1)	0.41 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
F10	6.6	1.3	0.08 (<1)	0.42 (<1)	-2.5 (<0.9)	-2.5 (<0.9)
G2	5.2	1.3	0.11 (<1)	0.50 (<1)	-1.6 (<0.9)	-1.2 (<0.9)
G3	5.2	1.3	0.11 (<1)	0.49 (<1)	-1.7 (<0.9)	-1.5 (<0.9)
G5	5.3	1.3	0.11 (<1)	0.46 (<1)	-1.8 (<0.9)	-1.8 (<0.9)
G10	5.4	1.3	0.10 (<1)	0.48 (<1)	-2.1 (<0.9)	-2.2 (<0.9)
B2	5.6	1.2	0.08 (<1)	0.44 (<1)	-1.6 (<0.9)	-1.3 (<0.9)
B3	5.7	1.2	0.08 (<1)	0.44 (<1)	-1.8 (<0.9)	-1.6 (<0.9)
B5	5.8	1.2	0.08 (<1)	0.44 (<1)	-1.9 (<0.9)	-1.8 (<0.9)
B10	5.8	1.3	0.10 (<1)	0.44 (<1)	-1.9 (<0.9)	-1.9 (<0.9)
C10	6.6	1.3	0.03 (<1)	0.44 (<1)	-1.5 (<0.9)	-1.5 (<0.9)

1. The Kwiatkowski et al. (1992) test of I(0), against I(1)
2. Lo's (1991) R/S test for I(0) against I(d), for d > 0 or d < 0.
3. The augmented Dickey-Fuller test of I(1) vs I(0). The number of lags is chosen to optimize the Schwarz information criterion over the range 0 to [T^1/3].
4. Phillips-Perron (1988) test of I(1) against I(0).

Table B2: Stationarity Tests on De-Trended Data (Whole Sample)

Rate	Ho: I(0) (stationary)		Ho: I(1) (non-stationary)	
	KPSS[1]	Lo's RS[2]	ADF[3]	P-P[4]
SVR	0.23 (<0.01)	1.48 (<0.2)	-2.6 (<0.9)	-1.7 (<0.9)
DVR	0.39 (<0.01)	1.75 (<0.05)	-2.5 (<0.9)	-2.0 (<0.9)
LIBOR	0.24 (<0.01)	1.50 (<0.2)	-2.0 (<0.9)	-1.5 (<0.9)
G1	0.15 (<0.05)	1.32 (<0.4)	-2.5 (<0.9)	-1.5 (<0.9)
P1	0.16 (<0.05)	1.24 (<0.5)	-2.6 (<0.9)	-1.4 (<0.9)
B1	0.20 (<0.025)	1.32 (<0.4)	-1.8 (<0.9)	-1.5 (<0.9)
F2	0.44 (<0.01)	1.95 (<0.025)	-2.9 (<0.9)	-2.6 (<0.9)
F3	0.45 (<0.01)	2.06 (<0.025)	-2.7 (<0.9)	-2.6 (<0.9)
F5	0.52 (<0.01)	2.19 (<0.005)	-2.7 (<0.9)	-2.4 (<0.9)
F10	0.58 (<0.01)	2.33 (<0.005)	-2.2 (<0.9)	-2.1 (<0.9)
G2	0.18 (<0.025)	1.31 (<0.4)	-3.1 (<0.1)	-2.3 (<0.9)
G3	0.23 (<0.01)	1.49 (<0.2)	-3.4 (<0.1)	-2.7 (<0.9)
G5	0.35 (<0.01)	1.90 (<0.025)	-2.9 (<0.9)	-2.8 (<0.9)
G10	0.52 (<0.01)	2.27 (<0.005)	-2.3 (<0.9)	-2.3 (<0.9)
B2	0.21 (<0.025)	1.43 (<0.3)	-3.0 (<0.9)	-2.3 (<0.9)
B3	0.22 (<0.01)	1.44 (<0.3)	-3.3 (<0.1)	-2.7 (<0.9)
B5	0.29 (<0.01)	1.68 (<0.1)	-3.2 (<0.1)	-2.9 (<0.9)
B10	0.43 (<0.01)	2.19 (<0.005)	-2.5 (<0.9)	-2.5 (<0.9)
C10	0.49 (<0.01)	2.27 (<0.005)	-0.8 (<0.975)	-0.9 (<0.975)

1. The Kwiatkowski et al. (1992) test of I(0), against I(1)
2. Lo's (1991) R/S test for I(0) against I(d), for d > 0 or d < 0.
3. The augmented Dickey-Fuller test of I(1) against I(0). The number of lags is chosen to optimize the Schwarz information criterion over the range 0 to [T^1/3].
4. Phillips-Perron (1988) test of I(1) against I(0).

Table B3: Stationarity Tests on Underlying Data (Pre-Crisis)

Rate	Mean	S.D.	Ho: I(0) (stationary)		Ho: I(1) (non-stationary)	
			KPSS[1]	Lo's RS[2]	ADF[3]	P-P[4]
SVR	7.0	1.0	0.02 (<1)	0.28 (<1)	-2.1 (<0.9)	-1.7 (<0.9)
DVR	3.7	2.4	0.29 (<1)	1.11 (<0.7)	-1.9 (<0.9)	-1.9 (<0.9)
LIBOR	5.4	1.1	0.06 (<1)	0.43 (<1)	-1.9 (<0.9)	-1.5 (<0.9)
G1	5.2	1.0	0.06 (<1)	0.41 (<1)	-2.0 (<0.9)	-1.5 (<0.9)
P1	5.3	1.1	0.06 (<1)	0.42 (<1)	-1.9 (<0.9)	-1.4 (<0.9)
B1	5.5	1.1	0.06 (<1)	0.43 (<1)	-1.7 (<0.9)	-1.4 (<0.9)
F2	5.9	1.1	0.07 (<1)	0.40 (<1)	-2.6 (<0.1)	-2.6 (<0.9)
F3	6.2	1.1	0.06 (<1)	0.37 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
F5	5.9	1.3	0.08 (<1)	0.40 (<1)	-2.5 (<0.9)	-2.5 (<0.9)
F10	6.7	1.4	0.09 (<1)	0.41 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
G2	5.4	1.1	0.07 (<1)	0.42 (<1)	-2.4 (<0.9)	-2.3 (<0.9)
G3	5.4	1.1	0.08 (<1)	0.41 (<1)	-2.5 (<0.9)	-2.5 (<0.9)
G5	5.5	1.2	0.08 (<1)	0.41 (<1)	-2.6 (<0.1)	-2.6 (<0.1)
G10	5.5	1.3	0.09 (<1)	0.47 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
B2	5.7	1.1	0.06 (<1)	0.40 (<1)	-2.3 (<0.9)	-2.3 (<0.9)
B3	5.8	1.1	0.06 (<1)	0.40 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
B5	5.9	1.1	0.07 (<1)	0.39 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
B10	6.0	1.2	0.08 (<1)	0.39 (<1)	-2.3 (<0.9)	-2.3 (<0.9)
C10	6.4	1.2	0.06 (<1)	0.36 (<1)	-2.3 (<0.9)	-2.3 (<0.9)

1. The Kwiatkowski et al. (1992) test of I(0), against I(1)
2. Lo's (1991) R/S test for I(0) against I(d), for d > 0 or d < 0.
3. The augmented Dickey-Fuller test of I(1) vs I(0). The number of lags is chosen to optimize the Schwarz information criterion over the range 0 to [T^1/3].
4. Phillips-Perron (1988) test of I(1) against I(0).

Table B4: Stationarity Tests on De-Trended Data (Pre-Crisis)

Rate	Ho: I(0) (stationary)		Ho: I(1) (non-stationary)	
	KPSS[1]	Lo's RS[2]	ADF[3]	P-P[4]
SVR	0.02 (<1)	0.28 (<1)	-2.1 (<0.9)	-1.7 (<0.9)
DVR	0.43 (<0.01)	1.78 (<0.05)	-1.5 (<0.9)	-1.4 (<0.9)
LIBOR	0.06 (<1)	0.43 (<1)	-1.9 (<0.9)	-1.5 (<0.9)
G1	0.06 (<1)	0.41 (<1)	-2.0 (<0.9)	-1.5 (<0.9)
P1	0.06 (<1)	0.42 (<1)	-1.9 (<0.9)	-1.4 (<0.9)
B1	0.06 (<1)	0.43 (<1)	-1.7 (<0.9)	-1.4 (<0.9)
F2	0.32 (<0.01)	1.63 (<0.1)	-2.0 (<0.9)	-2.0 (<0.9)
F3	0.33 (<0.01)	1.73 (<0.1)	-2.3 (<0.9)	-1.9 (<0.9)
F5	0.38 (<0.01)	1.85 (<0.05)	-1.6 (<0.9)	-1.5 (<0.9)
F10	0.46 (<0.01)	2.13 (<0.005)	-1.6 (<0.9)	-1.7 (<0.9)
G2	0.07 (<1)	0.42 (<1)	-2.4 (<0.9)	-2.3 (<0.9)
G3	0.08 (<1)	0.41 (<1)	-2.5 (<0.9)	-2.5 (<0.9)
G5	0.08 (<1)	0.41 (<1)	-2.6 (<0.1)	-2.6 (<0.1)
G10	0.09 (<1)	0.47 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
B2	0.06 (<1)	0.40 (<1)	-2.3 (<0.9)	-2.3 (<0.9)
B3	0.06 (<1)	0.40 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
B5	0.07 (<1)	0.39 (<1)	-2.4 (<0.9)	-2.4 (<0.9)
B10	0.08 (<1)	0.39 (<1)	-2.3 (<0.9)	-2.3 (<0.9)
C10	0.06 (<1)	0.36 (<1)	-2.3 (<0.9)	-2.3 (<0.9)

1. The Kwiatkowski et al. (1992) test of I(0), against I(1)
2. Lo's (1991) R/S test for I(0) against I(d), for d > 0 or d < 0.
3. The augmented Dickey-Fuller test of I(1) against I(0). The number of lags is chosen to optimize the Schwarz information criterion over the range 0 to [T^1/3].
4. Phillips-Perron (1988) test of I(1) against I(0).

C Cointegration Tests

Appendix C presents the Eigenvalue and Trace tests for cointegration between the 17 analysed relationships, assuming both the null hypothesis of no cointegration (rank=0), and full cointegration (rank=1). Across the whole sample, the null hypothesis of cointegration is never rejected, and for the discounted mortgage rate relationships the null of no cointegration is firmly rejected. For the pre-sample period, the null of no cointegration is rejected for all except the standard variable-rate relationships, the relationship between 3-year fixed- and 3-year interbank-rates, and 10-year fixed- and corporate bond rates. The null of full cointegration is rejected only for 3 of the discounted variable-rate relationships.

Table C1: Cointegration Tests (Whole Sample)

Relationship	UVAR Lag Selection[1]	Max Eigenvalue Test Ho: r=0	Max Eigenvalue Test Ho: r=1	Trace Test Ho: r=0	Trace Test Ho: r=1
F2-G2	2	10.4 (<0.5)	1.6 (<1)	11.9 (<0.5)	1.6 (<1)
F3-G3	3	9.5 (<0.5)	3.8 (<0.5)	13.3 (<0.5)	3.8 (<0.5)
F5-G5	3	8.6 (<0.5)	1.8 (<1)	10.4 (<1)	1.8 (<1)
F10-G10	3	13.1 (<0.2)	5.4 (<0.5)	18.5 (<0.1)	5.4 (<0.5)
F2-B2	2	11.7 (<0.2)	2.8 (<1)	14.4 (<0.5)	2.8 (<1)
F3-B3	3	10.1 (<0.5)	5.0 (<0.5)	15.1 (<0.5)	5.0 (<0.5)
F5-B5	3	9.4 (<0.5)	3.7 (<0.5)	13.1 (<0.5)	3.7 (<0.5)
F10-B10	2	13.9 (<0.1)	4.5 (<0.5)	18.3 (<0.1)	4.5 (<0.5)
F10-C10	3	10.6 (<0.5)	1.0 (<1)	11.6 (<0.5)	1.0 (<1)
SVR-LIBOR	3	15.4 (<0.1)	3.4 (<0.5)	18.8 (<0.1)	3.4 (<0.5)
SVR-G1	4	10.4 (<0.5)	1.2 (<1)	11.6 (<0.5)	1.2 (<1)
SVR-B1	4	14.3 (<0.1)	3.4 (<1)	17.7 (<0.2)	3.4 (<1)
SVR-P1	2	10.2 (<0.5)	2.2 (<1)	12.4 (<0.5)	2.2 (<1)
DVR-LIBOR	11	359.3 (<0.01)	4.3 (<0.5)	363.6 (<0.01)	4.3 (<0.5)
DVR-G1	7	203.2 (<0.01)	3.4 (<0.5)	206.6 (<0.01)	3.4 (<0.5)
DVR-B1	9	331.1 (<0.01)	3.4 (<1)	334.5 (<0.01)	3.4 (<1)
DVR-P1	3	167.0 (<0.01)	7.6 (<0.1)	174.5 (<0.01)	7.6 (<0.1)

1. Selected with the Schwarz Information Criterion.

Table C2: Cointegration Tests (Pre-Crisis)

Relationship	UVAR Lag Selection[1]	Max Eigenvalue Test Ho: r=0	Max Eigenvalue Test Ho: r=1	Trace Test Ho: r=0	Trace Test Ho: r=1
F2-G2	1	45.6 (<0.01)	5.8 (<0.5)	51.4 (<0.01)	5.8 (<0.5)
F3-G3	2	52.2 (<0.01)	7.4 (<0.2)	59.6 (<0.01)	7.4 (<0.2)
F5-G5	3	14.2 (<0.1)	7.5 (<0.2)	21.7 (<0.05)	7.5 (<0.2)
F10-G10	2	16.8 (<0.05)	6.2 (<0.2)	23.1 (<0.025)	6.2 (<0.2)
F2-B2	3	17.2 (<0.05)	6.0 (<0.2)	23.2 (<0.025)	6.0 (<0.2)
F3-B3	3	15.1 (<0.1)	5.9 (<0.5)	20.9 (<0.05)	5.9 (<0.5)
F5-B5	3	19.3 (<0.025)	7.5 (<0.1)	26.8 (<0.01)	7.5 (<0.1)
F10-B10	2	21.9 (<0.01)	6.9 (<0.2)	28.8 (<0.01)	6.9 (<0.2)
F10-C10	2	11.7 (<0.2)	5.8 (<0.5)	17.4 (<0.2)	5.8 (<0.5)
SVR-LIBOR	4	14.2 (<0.1)	2.2 (<1)	16.4 (<0.2)	2.2 (<1)
SVR-G1	4	13.1 (<0.2)	3.2 (<1)	16.3 (<0.2)	3.2 (<1)
SVR-B1	5	10.3 (<0.5)	2.6 (<1)	12.9 (<0.5)	2.6 (<1)
SVR-P1	3	11.8 (<0.2)	2.2 (<1)	14.0 (<0.5)	2.2 (<1)
DVR-LIBOR	3	334.7 (<0.01)	10.6 (<0.05)	345.3 (<0.01)	10.6 (<0.05)
DVR-G1	3	308.5 (<0.01)	11.4 (<0.025)	319.9 (<0.01)	11.4 (<0.025)
DVR-B1	4	338.9 (<0.01)	2.8 (<1)	341.7 (<0.01)	2.8 (<1)
DVR-P1	3	316.3 (<0.01)	10.2 (<0.05)	326.5 (<0.01)	10.2 (<0.05)

1. Selected with the Schwarz Information Criterion.

D Lag and Lead Selection

I follow the suggestion of Choi and Kurozumi (2008) to use information criteria, and specifically their simplified Cp criterion (see Mallows (2000)) which minimises bias in simulations. This criterion is given by:

$$C_p = \frac{1}{\widehat{\sigma}_\varepsilon^2} \sum_{t=l+2}^{T-u} \widehat{e}_{t,u}^2 + (p+1)(l+u+2) - T, \tag{6}$$

where $\widehat{\sigma}_\varepsilon^2 = \frac{1}{T-u_{\max}-l_{\max}} \sum_{t=l_{\max}+2}^{T-u_{\max}} \widehat{e}_{t,u_{\max}}^2$ and subscripts l and u refer to the number of lags and leads respectively. $l_{\max}$ and $u_{\max}$ are their upper limits, chosen with the suggested function of the sample size, $T^{\frac{1}{4}} \approx 4$. Table D1 shows, for all 17 estimated relationships, the selected P-L model with the chosen number of lags and leads in parentheses (for example, a PL(2,1) model contains 2 lags and 1 lead), together with those chosen with BIC and AIC criteria for the sensitivity analysis. Table D2 shows the estimated parameters for the cases where minimising BIC and AIC resulted in different lags and leads.

Table D1: Model Selection Criteria

	PL(L,U) Model Minimised with respect to:				PL(L,U) Model Minimised with respect to:		
Relationship	Cp	BIC	AIC	Relationship	Cp	BIC	AIC
Standard Variable Rates				**Fixed Rates**			
SVR-P1	(4,4)	(1,0)	(4,4)	FR2-G2	(2,1)	(1,0)	(1,0)
SVR-G1	(4,4)	(3,2)	(4,4)	FR3-G3	(4,3)	(2,1)	(2,1)
SVR-LIBOR	(4,4)	(2,1)	(4,4)	FR5-G5	(4,4)	(2,1)	(2,1)
SVR-B1	(4,4)	(2,1)	(4,4)	FR10-G10	(2,1)	(2,1)	(2,1)
Discounted Variable Rates							
DVR-P1	(4,4)	(1,0)	(1,0)	FR2-B2	(2,1)	(1,0)	(2,1)
DVR-G1	(4,4)	(1,0)	(1,1)	FR3-B3	(2,1)	(2,1)	(2,1)
DVR-LIBOR	(4,3)	(1,0)	(4,3)	FR5-B5	(4,4)	(1,0)	(2,1)
DVR-B1	(4,4)	(1,0)	(4,4)	FR10-B10	(2,2)	(1,0)	(2,2)
				FR10-C10	(2,1)	(2,1)	(2,1)

Table D2: Long Run Model Lag Sensitivity Checks

Relationship	Pre-Crisis[1]		Post-Crisis Effect		R^2	DW	Ho: Complete Pass Through[2]	
	Constant	Slope	Constant	Slope			Pre-Crisis	Post-Crisis
Standard Variable Rates								
SVR-P1 PL(1,0)	2.67^{c}	0.80^{c}	$+0.26^{c}$	-0.04^{c}	1.00	2.06	0.000	0.000
	(11.5)	(18.6)	(4.6)	(-3.9)				
SVR-G1, PL(3,2)	2.34^{c}	0.88^{c}	$+0.26^{b}$	-0.04^{a}	0.99	2.06	0.015	0.001
	(9.3)	(18.5)	(3.0)	(-2.2)				
SVR-LIBOR, PL(2,1)	2.30^{c}	0.85^{c}	+0.05	-0.01	0.99	2.06	0.008	0.002
	(7.5)	(15.4)	(p=0.645)	(p=0.404)				
SVR-B1, PL(2,1)	2.31^{c}	0.85^{c}	-0.05	+0.01	0.99	2.2	0.000	0.000
	(9.7)	(19.8)	(p=0.524)	(p=0.656)				
Discounted Variable Rates								
DVR-P1, PL(1,0)	0.23	0.97^{c}	$+0.71^{c}$	-0.10^{c}	0.99	2.07	0.523	0.007
	(p=0.403)	(18.0)	(4.2)	(-3.6)				
DVR-G1, PL(1,0)	-0.11	1.06^{c}	$+0.74^{c}$	-0.11^{c}	0.99	1.97	0.237	0.971
	(p=0.663)	(20.7)	(5.3)	(-4.2)				
DVR-G1, PL(1,1)	-0.02	1.04^{c}	$+0.72^{c}$	-0.11^{c}	0.99	1.98	0.399	0.961
	(p=0.930)	(21.1)	(5.1)	(-4.2)				
DVR-LIBOR, PL(1,0)	0.18	0.96^{c}	$+0.63^{c}$	-0.11^{c}	0.99	1.93	0.336	0.000
	(p=0.409)	(22.4)	(4.9)	(-4.6)				
DVR-B1, PL(1,0)	0.08	0.97^{c}	$+0.54^{c}$	-0.09^{c}	0.99	1.88	0.564	0.008
	(p=0.754)	(20.6)	(4.6)	(-4.0)				
Fixed Rates								
F2-G2, PL(1,0)	0.63^{b}	0.98^{c}	0.63	-0.08^{b}	0.98	1.94	0.547	0.008
	(3.0)	(25.2)	(4.4)	(-2.8)				
F3-G3, PL(2,1)	1.00^{c}	0.95^{c}	$+0.53^{c}$	-0.07^{a}	0.98	1.98	0.039	0.000
	(4.9)	(25.4)	(3.5)	(-2.2)				
F5-G5, PL(2,1)	0.64^{a}	1.04^{c}	$+0.50^{c}$	-0.08^{a}	0.99	2.02	0.428	0.359
	(2.5)	(22.4)	(3.3)	(-2.6)				
F2-B2, PL(1,0)	0.29	0.98^{c}	$+0.48^{b}$	-0.07^{a}	0.98	1.99	0.567	0.023
	(p=0.240)	(23.2)	(3.4)	(-2.5)				
F5-B5, PL(1,0)	0.02	1.07^{c}	$+0.72^{c}$	-0.12^{c}	0.99	1.94	0.014	0.115
	(p=0.881)	(40.0)	(5.2)	(-4.5)				
F5-B5, PL(2,1)	0.04	1.06^{c}	$+0.65^{c}$	-0.11^{c}	0.99	2.02	0.062	0.261
	(p=0.860)	(30.8)	(4.6)	(-4.0)				
F10-B10, PL(1,0)	0.02	1.07^{c}	$+0.72^{c}$	-0.12^{c}	0.99	1.94	0.208	0.265
	(p=0.881)	(39.5)	(5.2)	(-4.5)				

1. Pre-crisis includes monthly observations from Jan 1995 up to and including July 2007, post-crisis from August 2007 to May 2009.
2. P-values for a Chi-Squared Test with Slope Coefficient restricted =1 (small value indicates evidence for incomplete pass through)
Significance levels of 5%, 1%, and 0.1% are indicated by superscript a, b, and c respectively, numbers in brackets indicate t-ratios except for insignificant coefficients, for which associated p-values are given instead.

E Mean Adjustment Lag Calculation

This appendix shows how Mean Adjustment Lags (MALs) are calculated following Hendry (1995), for a short run equation that is initially specified in error correction form. The general form for our $SR(x, y)$ model can be written as:

$$\Delta r_t = (\beta_0 + \beta_{00} D)\Delta i_t + \delta\varepsilon_{t-1} + E(L) + F(L) + v_t, \quad (7)$$

where constants in the disequilibrium term (which do not affect the system's dynamics) are not included; the error term (v_t) is assumed to be a stationary *iid* process (so can be ignored henceforth); and I define:

$$
\begin{aligned}
\delta &= \left((1-D)\left(\delta_1\lambda+\delta_2(1-\lambda)\right)+D\delta_3\right) && (8)\\
\varepsilon_t &= r_t-\alpha_1 i_t-\alpha_3 D i_t && (9)\\
E(L) &= \sum_{i=1}^{x}\beta_i\Delta i_{t-i} && (10)\\
F(L) &= \sum_{j=1}^{y}\gamma_j\Delta r_{t-j}. && (11)
\end{aligned}
$$

$E(L)$ and $F(L)$ are lag functions that depend on the (assumed finite) number of lags of the differenced exogenous (retail rate, r_t) and endogenous (wholesale rate, i_t) variables respectively.

From now on I use the standard lag notation, where $x_{t-i}=x_t[L^i]$

If we express the general form in levels with r_t on the LHS and i_t on the RHS:

$$r_t\left[A(L)\right]=i_t\left[B(L)\right], \tag{12}$$

then following the algebra on p.215 of Hendry (1995), the MAL formula is:

$$MAL=\frac{B^{'}(L)}{B(L)}-\frac{A^{'}(L)}{A(L)} \qquad \text{for } L=1, \tag{13}$$

where prime denotes the first derivative of the lag function with respect to L. Then equation 7 written in the levels form of equation 12 is:

$$
\begin{aligned}
r_t-r_{t-1}-\delta r_{t-1}-F(L) &= (\beta_0+\beta_{00}D)i_t-(\beta_0+\beta_{00}D)i_{t-1}-\delta\left(\alpha_1 i_{t-1}+\alpha_3 D i_{t-1}\right)+E(L)\\
r_t\left[1-L^1(1-\delta)-F(L)\right] &= i_t\left[(\beta_0+\beta_{00}D)-(\beta_0+\beta_{00}D)L^1-\delta L^1\left(\alpha_1+\alpha_3 D\right)+E(L)\right].
\end{aligned}
$$

We therefore have:

$$
\begin{aligned}
A(L) &= 1-L^1(1-\delta)-F(L)\\
A(L)^{'} &= -(1-\delta)-F^{'}(L)\\
B(L) &= \left[(\beta_0+\beta_{00}D)-(\beta_0+\beta_{00}D)L^1-\delta L^1\left(\alpha_1+\alpha_3 D\right)+E(L)\right]\\
B^{'}(L) &= -(\beta_0+\beta_{00}D)-\delta\left(\alpha_1+\alpha_3 D\right)+E^{'}(L),
\end{aligned}
$$

and so using formula 13 we have:

$$MAL=\frac{(\beta_0+\beta_{00}D)+\delta\left(\alpha_1+\alpha_3 D\right)-E^{'}(1)}{\delta\left(\alpha_1+\alpha_3 D\right)-E(1)}-\frac{(\delta-1)-F^{'}(1)}{\delta-F(1)}. \tag{14}$$

The functions $E(L)$ and $F(L)$ have the same form, which can be simplified for any similar differenced lag structure, say $G(L)$, in the following way:

$$\begin{aligned}
G(L) &= \sum_{i=1}^{n} \phi_i \Delta x_{t-i} \\
G(L) &= \phi_1 \Delta x_{t-1} + \phi_2 \Delta x_{t-2} ... + \phi_n \Delta x_{t-n} \\
G(L) &= \phi_1 (x_{t-1} - x_{t-2}) ... + \phi_n \Delta (x_{t-n} - x_{t-(n+1)}) \\
G(L) &= x_t \left[\phi_1 \left(L^1 - L^2 \right) ... + \phi_n \left(L^n - L^{n+1} \right) \right],
\end{aligned}$$

so for $L = 1$, all terms disappear and we simply have:

$$G(1) = 0. \tag{15}$$

Taking the first derivative of $G(L)$ with respect to L we have:

$$G^{'}(L) = x_t \left[\phi_1 (1 - 2L) + \phi_2 \left(2L - 3L^2 \right) + ... + \phi_n \left(nL^{n-1} - (n+1)L^n \right) \right],$$

which for $L = 1$ is:

$$\begin{aligned}
G^{'}(1) &= x_t \left[\phi_1 (1 - 2) + \phi_2 (2 - 3) + ... + \phi_n (n - (n+1)) \right] \\
G^{'}(1) &= x_t \left[-\phi_1 - \phi_2 - ... - \phi_n \right]
\end{aligned} \tag{16}$$

Substituting these results 15 and 16 into formula 14 we have:

$$MAL = 1 + \frac{(\beta_0 + \beta_{00} D) + \beta_1 + ... + \beta_x}{\delta (\alpha_1 + \alpha_3 D)} + \frac{(1 - \delta)}{\delta} - \frac{\gamma_1 + ... + \gamma_y}{\delta}. \tag{17}$$

For the pre/post-crisis analysis, where $\delta = (\delta_0 + \delta_{00} D)$, we can calculate the MAL for two cases:

Case A: Pre-Crisis Regime ($D = 0$), hence $\delta_a = \delta_0$

Case B: Post-Crisis Regime ($D = 1$), hence $\delta_b = \delta_0 + \delta_{00}$

$$MAL^a = 1 + \frac{\beta_0 + \beta_1 + ... + \beta_x}{\delta_a \alpha_1} + \frac{(1 - \delta_a)}{\delta_a} - \frac{\gamma_1 + ... + \gamma_y}{\delta_a} \tag{18}$$

$$MAL^b = 1 + \frac{(\beta_0 + \beta_{00} D) + \beta_1 + ... + \beta_x}{\delta_b (\alpha_1 + \alpha_3 D)} + \frac{(1 - \delta_b)}{\delta_b} - \frac{\gamma_1 + ... + \gamma_y}{\delta_b}. \tag{19}$$

For the asymmetry analysis we have $\delta = ((1 - D)(\delta_1 \lambda + \delta_2 (1 - \lambda)) + D\delta_3)$. There are two different cases for δ, depending on the particular equilibrium correction regime. For δ, as defined in equation 8, these are:

Case C: Pre-Crisis, Above Equilibrium Regime ($D = 0, \lambda = 1$), hence $\delta = \delta_1$

Case D: Pre-Crisis, Below Equilibrium Regime ($D = 0, \lambda = 0$), hence $\delta = \delta_2$

Using notation where MAL^{+} and MAL^{-} denote Mean Adjustment Lags for Case C and D respectively, we have our MAL formulae:

$$MAL^{+} = 1 + \frac{\beta_0 + \beta_1 + ... + \beta_x}{\delta\alpha_1} + \frac{(1-\delta_1)}{\delta_1} - \frac{\gamma_1 + ... + \gamma_y}{\delta_1} \tag{20}$$

$$MAL^{-} = 1 + \frac{\beta_0 + \beta_1 + ... + \beta_x}{\delta_2\alpha_1} + \frac{(1-\delta_2)}{\delta_2} - \frac{\gamma_1 + ... + \gamma_y}{\delta_2}. \tag{21}$$

Taking the example of a $SR(2,0)$ model, the mean adjustment lags are:

$$MAL^{+} = 1 + \frac{\beta_0 + \beta_1 + \beta_2}{\delta\alpha_1} + \frac{(1-\delta_1)}{\delta_1}$$

$$MAL^{-} = 1 + \frac{\beta_0 + \beta_1 + \beta_2}{\delta_2\alpha_1} + \frac{(1-\delta_2)}{\delta_2}.$$

F A Forward-Looking Model of Retail Rate-Setting

This appendix outlines the conceptual model of Hoffman(04), which provides an adjustment cost rationale for asymmetric adjustment of retail rates to changes in policy rates. Retail rates also depend on *forecasts* of policy rates, highlighting the potential for a relationship between current retail rates and *future* wholesale rates, and hence the potential importance of using the P-L estimator to allow for this.

First of all, it is suggested that Banks are able to adjust their retail rates every even period, whilst being able to make an additional adjustment in the following odd period, but only at a fixed cost c. The monetary authority makes a rate decision every even period, after which the bank sets its retail rates for the current and following period. The loss function for the bank is quadratic in the deviation of the retail rate from its desired level, so the optimal rate at time 0 is:

$$r_0^* = \frac{i_0 + E_0(i_1)}{2}. \tag{22}$$

Following this, unexpected shocks to the policy rate can cause the desired optimal retail rate to change (and in the even time period 1 where it costs the bank to make such an adjustment). Say that base rates can be forecasted up to a white noise error:

$$i_1 = E(i_1) + \varepsilon, \tag{23}$$

then at even time period 1 the bank would like to re-set to:

$$r_1^* = \frac{i_1 + E(i_2)}{2}.$$

There are two options for the bank at this point. Either it will be worth making this adjustment to r_1^*, if the gain from avoiding the quadratic loss outweighs the fixed marginal cost of adjustment, or not, in which case it will leave its rate unchanged at r_0^*. That is, adjustment is worth it when this condition is fulfilled:

$$E\left[(r_0^* - i_1)^2 - (r_1^* - i_1)^2 + (r_0^* - i_2)^2 - (r_1^* - i_2)^2\right] > c$$

This condition can then be manipulated to give:

$$\begin{aligned} 2(r_0^* - r_1^*)^2 &> c \\ [(r_0^* - r_1^*) - E\Delta i]^2 &> c \end{aligned}$$

The second term is the expected change in the base rate, $E\Delta i = \left(\frac{E_1 i_2 - i_1}{2}\right)$.This means that the bank will *not* adjust iff the difference between its previously set retail rate and the current base rate lies in a region around the expected change in the base rate

$$\left(\frac{E_1 i_2 - i_1}{2}\right) - \sqrt{\frac{c}{2}} < r_0^* - i_1 < \left(\frac{E_1 i_2 - i_1}{2}\right) + \sqrt{\frac{c}{2}}.$$

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