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In Search of a Risk-free Asset

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Abstract

To attract retail time deposits, over 7,000 FDIC insured U.S. commercial banks publicly post their yield offers. I document an economically sizable and highly procyclical cross-sectional dispersion in these yield offers during the period 1997 - 2011. Banks adjusted their yields rigidly and asymmetrically with median duration of 7 weeks in response to increasing or constant Fed Funds rate target regimes and 3 weeks during regimes of decreasing Fed Fund rate target. I investigate to what extent information (search) costs on the part of the investors in this market can explain the observed pricing behavior. I build and estimate an asset pricing model with heterogeneous search cost investors. A large fraction of high information cost uninformed investors and the exit of low information cost informed investors rationalizes the observed price dispersion. I further qualitatively match the asymmetric yield rigidity within the framework of costly consumer search without the need to impose menu costs or other restrictions on the banks' repricing behavior.

JEL Classification: D83, D91, G12, G21

Keywords: Consumer search,Price rigidity, Deposit rates, Interest rate pass-through

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1 Introduction

Since the seminal work by Stigler [1961], it is well understood that consumer search costs can generate first-order deviations in the behavior of prices, quantities and welfare in homogeneous product markets from what Walrasian theory would predict. While most of the theoretical and empirical work on consumer search has focused on non-financial retail markets, there has been little work done on financial markets. As long as there is active arbitrage, neither heterogeneity in the stochastic discount factor, nor heterogeneity in the information set of each investor would lead to deviations from the law of one price.

Two prominent examples of empirical proxies of default risk-free assets are U.S. government issued bonds and FDIC insured time deposits which are part of the M2 money aggregate. A U.S. treasury bond is nominally risk-less if held until maturity, and its pricing to first-order approximation abides by the law of one price [1]. The certificate of deposit contract is a standard contract offered by commercial banks which closely resembles a treasury bond. It carries the explicit insurance of the FDIC up to an insurance limit which makes its pay-offs insensitive to the credit risk of the underlying institution. As such, they are nominally risk-less if held until maturity and a homogeneous financial product.

In this paper, I use a novel proprietary database on the pricing of the retail certificates of deposits offered by the FDIC insured commercial banks between January 1997 and June 2011. I document a set of stylized facts on the pricing of these standard investment products which present a puzzle with respect to the standard asset pricing theory predictions. In Figure (1), I document the time series variation of the 5th/95th percentiles of the yields offered on the shortest 3-month and the longest 5-year maturity CD contracts by more than 5,000 banks in the dataset. As is immediately striking from this graph, there was a sizeable and persistent yield dispersion of these offers throughout the entire period. Moreover, the yield dispersion was pro-cyclical with respect to the level of interest rates. In 2007, when yields on the 3-month treasury bill peaked at 5 percentage points, the median difference between the yield offered by the banks in 90th and the the yield offered by banks in 10th percentile for the 3-month contract was 188 basis points and the maximal difference was as high as 377 basis points (see Table (1)). In addition to the sizeable price dispersion and despite the fact that all banks were subject to the same aggregate variation in the level of market interest rates, the deposit yields were rigid to adjust and price adjustments across

[1] A notable exception is the well-documented on-the-run-off-the-run spread puzzle (see Krishnamurthy [2002]). A somewhat related literature looks at violations of arbitrage due to search and matching frictions in over-the-counter markets. Feldhütter [2012] finds evidence for the violation of the law of one price in the OTC market for corporate bonds estimating a model of Duffie, Gârleanu, and Pedersen [2005]. Violations of the law of one price are also explored in markets where collateral constrains of arbitrageurs bind inducing a spread between assets of identical pay-offs. Garleanu and Pedersen [2011] document such violations using the CDS-bond basis during the recent financial crisis.

banks were not synchronized. The duration of yield adjustment spells was asymmetric between regimes when the fed funds target rate was decreased and regimes when the fed funds target rate was increased or remained constant. The median duration between yield adjustments for the 3-month contract in the former regime was 3 weeks and 7 weeks in the latter. Yield rigidity was also decreasing with maturity so that the 5 year contract median duration between yield adjustments varied between 1 and 3 weeks (see Table (2)).

The observed price dispersion, its cyclical properties and the underlying price rigidity present a challenge for standard asset pricing theory. Not only is an asset that is so closely related to a treasury bond priced so differently, as evidenced in Figure (1), but within the same asset class the individual suppliers sustained large price dispersion while competing in prices for a homogeneous financial product. The stylized pricing facts uncover a violation of the law of one price and the presence of monopoly power that commercial banks consistently exploited during the sample period in this large and highly competitive market.

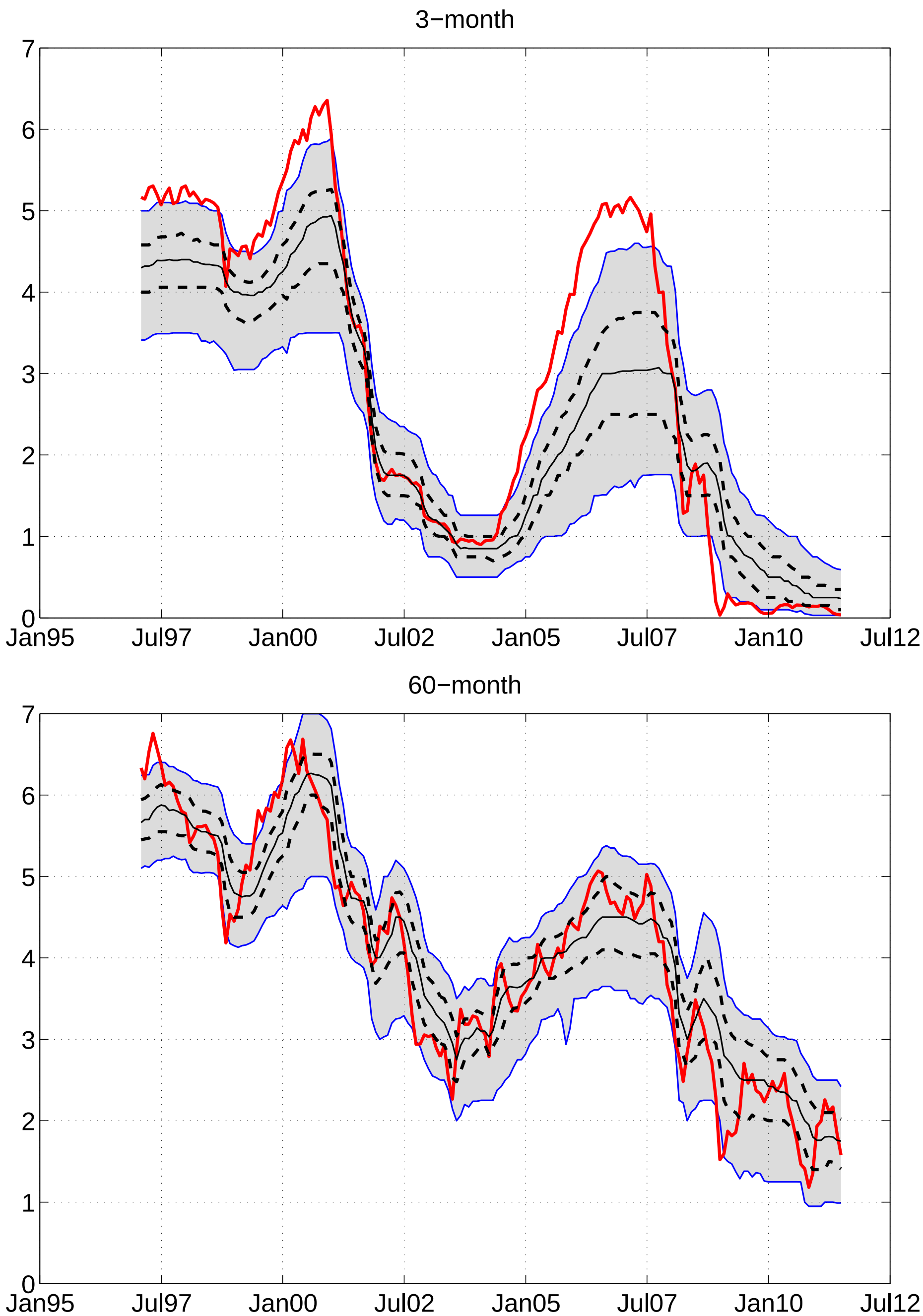
Understanding the retail nature of this market and the characteristics of the marginal investor are the key to finding a plausible explanation for the observed pricing behavior. In particular, I examine to the extent to which information costs on the part of the investors in this market as first conjectured by Stigler [1961] could be the source of the monopoly power, and the resulting price dispersion and price rigidity. I view the information cost heterogeneity more broadly as differences among household investors in their financial literacy (see Lusardi, Mitchell, and Curto [2010]) and their cognitive capacity to make financial decisions (see Agarwal, Driscoll, Gabaix, and Laibson [2009])

I build an asset pricing model with investors who are heterogeneous with respect to their search costs of obtaining information on the best returns on their savings. The presence of information costs on the part of the investors allows banks to sustain yield dispersion as an equilibrium of Burdett and Judd [1983]. [2] The heterogeneity of the information costs of the investors segments the market into distinct groups of investors according to the intensity of their search effort. Each segment obtains different ex-post information about the available best offers and the segments with high search costs remain rationally inattentive to the presence of better return on their savings. It is the relative size of this segment of rationally inattentive investors which determines the equilibrium price dispersion, monopoly profits and the degree of interest rate pass-through of market interest rates onto retail deposit rates.

Although the pricing of the retail certificates of deposit seems inconsistent with the pricing of financial assets, it resembles patterns observed in the pricing of non-financial products. As a result, the findings in this paper provide an empirical test of a relatively

[2] This paper builds on a large and growing theoretical and empirical literature that rationalizes the observed price dispersion in homogeneous product markets with the presence of costly information acquisition. An excellent summary can be found in Baye, Morgan, and Scholten [2006]

Figure 1: The time series of the cross-sectional distribution of CD yields



NOTE: The shaded area is the 5th and 95th percentile of the CD yield distribution. The black (thin) continuous line is the median of the distribution. The black dashed lines are the 25th and the 75th percentiles of the distribution. The red (thick) line is the matched maturity treasury yield.
SOURCE: RateWatch

unexplored theory on the source of price rigidity. I show that the model can generate the asymmetric price adjustment and price rigidity in the data. I examine a hypothesis first eloquently articulated by Head, Liu, Menzio, and Wright [2012] that price dispersion and price rigidity can be the outcome of a model of costly consumer search without technological restrictions on the ability of producers to adjust prices as in Calvo [1983] or the menu cost models such as Dotsey, King, and Wolman [1999]. A dynamic extension of the static framework of the Burdett-Judd equilibrium and an appropriately chosen repricing policy can endogenously generate the price rigidity, and the unsynchronized and asymmetric price adjustments that characterized the observed pro-cyclical price dispersion in the data. Unlike the Calvo-style price setting or the menu cost models, however, the producers in a costly consumer search market face no costs to adjust prices but choose not to adjust as they have no incentive to do so. This form of price rigidity leads to a specific nature of an incomplete pass-through of monetary policy shocks onto the financial system which is distinctly different from competing theories based on constraints on the producer side.

In the second part of the paper, I estimate the underlying search cost distribution and the intensity of search for the best yield in this market using the methodology of Hong and Shum [2006] and Moraga-González and Wildenbeest [2008] which allows me to estimate the search cost distribution using only the information contained in yield offer distribution. The model is able to fit reasonably well the observed price distributions for a number of years in the sample. The estimated search cost distribution suggests that investors in the market could be roughly split in two distinct groups - an uniformed group facing large search costs and an informed group of investors with low search costs who through their search effort are able to observe the best offers in the distribution. More than one third of the investors in the market implied by the model were the uninformed investors. These investors had search costs in the magnitude of 10-50 basis points and searched only once from the yield distribution. This group of investors who remained uniformed about the availability of better offers was responsible for the ability of banks to post different yields on their time deposits and sustain positive mark-ups over marginal costs. On the other end of the search cost spectrum, the share of informed investors has declined during the sample period from 20 percent of the sample to below 10 percent. Over the sample period, the dispersion in the search costs and median search cost have both increased. The median search cost has increased from 8 basis points in the earlier 1997-2000 period to 14 basis points in the 2001-2007 period. These trends are puzzling as over the period there was rapid introduction of Internet technologies such as Internet banking and rate comparison websites that should have reduced the information acquisition costs in these markets. The investors in these markets who are mainly elderly households, however, have not taken full advantage of these opportunities.

The increase in the median search costs and the exit of low information cost informed investors implied by the structural estimates of the model are closely related to findings in Hortaçsu and Syverson [2004] which documents the existence of sizable price dispersion in the fees charged by the retail S & P 500 mutual funds as well as the closely related to the insured deposit markets retail money market mutual funds. They attribute the existence of price dispersion and the proliferation of these funds to the presence of search costs on the part of the investors in this market as well as the entry of high information cost novice investors. These stylized facts in the mutual funds industry mirror the somewhat unexpected findings in this paper for the time deposit market. These common trends could be due to the exit of the low information cost investors from the traditional deposit markets and their entry into the relatively new retail mutual funds markets where these novice investors faced large information costs.

The documented stylized facts on the pricing of retail deposits extend results from previous empirical studies of the pricing of certificates of deposits. Diebold and Sharpe [1990] examine the pass-through of wholesale interest rates into the pricing of retail deposit rates in the immediate post-Regulation Q period [3] and are the first to document the rigid response of retail deposit rates to the variation in the wholesale market interest rates. Hannan and Berger [1991] and Neumark and Sharpe [1992] document the asymmetric price rigidity of deposit rates to changes in the marginal cost of funds of banks in the form of downward price rigidity and upward price flexibility and relate the magnitude of these rigidities to the degree of local market competition. The recent work by Driscoll and Judson [2013] extends the previous literature with more recent micro-panel data of deposit rates to further test theories on price setting behavior. Their conclusion is that the existing models of price rigidity face a challenge in fitting some of the unique characteristics of the price setting behavior of deposit rates. I contribute to this existing literature first, by introducing a much more detailed micro-level dataset and second, by providing a theoretical framework that can match the asset pricing facts. Unlike the existing literature, however, the focus in this paper is on the resulting price dispersion and its time-variation, both of which have not been previously explored.

The rest of the paper has the following structure. The next section (2) describes the RateWatch survey data. It documents the stylized pricing facts in detail and provides information on the characteristics of the certificate of deposit contract as well as describes the average investor in this market using data from the Survey of Consumer Finances. It also provides some indirect evidence on the degree to which investors searched among

[3] The Depository Institutions Deregulation and Monetary Control Act of 1980 gradually removed all restrictions on interest rates paid on savings accounts and time deposits by 1986. The prohibition to pay interest on demand deposits was only repealed in 2010 by the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010

alternatives. Section (3) presents the baseline model and explores the ability of the model to generate the observed price adjustments facts in a simple dynamic extension of the static equilibrium with monetary policy changing the cost of funds of banks. Sections (4.1) and (4.2) present the empirical implementation and the results from the structural estimation. Finally, section (6) concludes.

2 Data

I employ a novel proprietary database constructed by RateWatch[4] which contains the yields on the certificates of deposit (CDs) at weekly frequency over the period of 1997-2011 offered by approximately 5,726 U.S. FDIC insured commercial banks in 75, 879 local branch offices in over 10,000 cities across the US covering all 366 Metropolitan Statistical Areas (MSA). Over the same period the average number of operating commercial banks was around 7,500 in 2010 which guarantees a good coverage of the universe of banks. The dataset is constructed and maintained by RateWatch and contains both insured deposits of denomination less that hundred thousand dollars and non-insured large denomination deposits of amounts above one hundred thousand. This cut-off value is a standard for the industry and until 2008 distinguished insured time deposits from non-insured before the limit of \$ 100, 000 was increased to \$ 250, 000 thousand.

For the purpose of this study I focus only on the small denomination CDs as these were consistently covered by the FDIC insurance. The yield information on deposits of denomination less than $\$100,000$ is almost consistently covered by all banks in the sample. I also focus on banks that had offices in at least one of the 366 MSA areas. As a result the sample of banks is reduced to 3,796 as I exclude a number of small community banks that operate in small towns not included in a MSA area.

Information on the industry concentration, number of banks and number of branches at the MSA level is obtained from the Summary of Deposit database (SOD) [5]. Balance sheet and income statement information on the set of commercial banks is constructed from the Reports of Condition and Income (a.k.a. Call Reports)[6]. I also construct data from 2007 the Survey of Consumer Finances [7] to obtain information about actual CD holdings. Demographic and income information for the MSA markets is downloaded from the Census Bureau[8]. Finally, data on the return on the S& P 500 stock market index and the treasury market are obtained from CRSP [9]

[4]http://www.rate-watch.com/
[5]http://www2.fdic.gov/sod/
[6]https://cdr.ffiec.gov/public/
[7]http://www.federalreserve.gov/econresdata/scf/scf_2007.htm
[8]http://www.census.gov/main/www/access.html
[9]http://www.crsp.com/documentation/index.html

2.1 Stylized facts on the pricing of the insured certificates of deposit

The *first* prominent feature of the pricing of time deposits is the large and time-varying yield dispersion. To give perspective on the economic significance of the yield dispersion shown in Figure (1), Table (1) summarizes the distribution of a measure of the yield dispersion across the 366 MSA deposit markets for two years in the sample - 2003 when the level of market interest rates was low and 2007 when the level of interest rates was high. In 2003, market interest rates were low - the average 12-month treasury yield was 124 basis points, and so were the level of interest rates on time deposits and the observed price dispersion. The yield posted in the median MSA market for the 12-month CD contract was 153 basis points and the median price dispersion measure $DISP_{m,t} = P(0.9) - P(0.1)$ was 78 basis points.

During 2007, market interest rates were high - the 12-month treasury yield was 452 basis points, while the median yield posted on the 12-month CD contract was 402 basis points and median price dispersion measured at 147 basis points. In 2003, if an investor in the median MSA market in terms of price dispersion invested in a 12-month CD at the lowest 10th percentile as compared to investing in the highest 90th percentile, she would have sustained a loss of 78 dollars on the median investment of 10,000 for a CD contract. This hypothetical loss doubled to 147 dollars in 2007.

The amount of savings over the term of the contract an investor would make if she picked the top 90th percentile for the 5-year contract as compared to the bottom 10th percentile for the 5-year contract were even larger. In 2003 the difference between the total interest promised on a 10,000 dollar investment between the banks' offers in the 90th and the bank offers in 10th percentile for the median MSA was 478 dollars while in 2007 it increased to 568 dollars. The estimates are based on the price dispersion observed in the median market and for the markets with the highest dispersion in the yields the foregone interest payments are more than twice the size of the median. These large forgone gains are an example of violation of arbitrage in these financial markets.

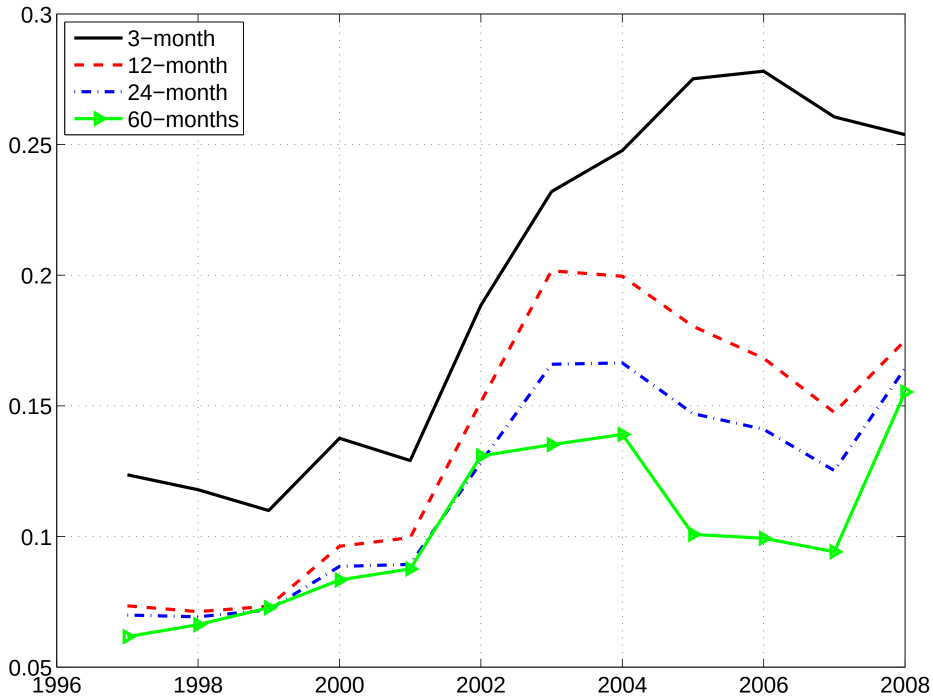
In order to control for the changing level of interest rates, Figure (2) plots the annual coefficient of variation for a select set of the maturities. As can be seen in the graph, the dispersion of the yields relative to their mean trended up for the period 1997-2008 prior to the financial crisis. The most pronounced absolute increase in the coefficient of variation was observed for the 3-month contract which more than doubled over this period from 0.12 to 0.27. Similar trends were observed for all maturities. For the 5-year contract, for example, this measure increased from 0.06 in 1997 to 0.1 in 2006 which were two years with high levels of interest rates.

Table 1: The distribution of the level (median) and the dispersion $P(0.9) - P(0.1)$ of CD yields across MSA markets for 2003 and 2007

			2003			
Median yield	3-month	6-month	12-month	24-month	36-month	60-month
min	0.61	0.84	1.14	1.55	1.80	2.65
p25	0.88	1.10	1.43	2.02	2.52	3.25
p50	0.95	1.18	1.53	2.12	2.61	3.37
p75	1.01	1.27	1.61	2.23	2.71	3.46
max	1.30	1.59	1.97	2.49	2.94	3.71
P(0.9)-P(0.1)	3-month	6-month	12-month	24-month	36-month	60-month
min	0.04	0.16	0.24	0.19	0.07	0.00
p25	0.43	0.53	0.63	0.67	0.71	0.81
p50	0.54	0.65	0.78	0.85	0.89	0.98
p75	0.69	0.80	0.93	1.05	1.10	1.25
max	1.37	1.37	1.62	1.66	1.96	2.46
			2007			
Median yield	3-month	6-month	12-month	24-month	36-month	60-month
min	1.82	2.53	2.78	3.19	3.29	3.36
p25	2.72	3.44	3.82	3.90	3.95	4.14
p50	2.98	3.67	4.02	4.06	4.09	4.29
p75	3.27	3.87	4.20	4.22	4.26	4.42
max	3.98	4.58	4.81	4.84	4.93	4.93
P(0.9)-P(0.1)	3-month	6-month	12-month	24-month	36-month	60-month
min	0.37	0.62	0.39	0.07	0.05	0.25
p25	1.45	1.52	1.20	1.04	1.04	0.98
p50	1.88	2.00	1.47	1.31	1.25	1.17
p75	2.34	2.29	1.79	1.58	1.51	1.37
max	3.77	3.26	3.30	3.24	2.41	2.16

NOTE: The table computes the distribution of the level of yields across the 366 MSA markets as well as the distribution of the measure of dispersion of yields within a market as measured by $DISP_{m,t} = P(0.9) - P(0.1)$ - the difference between the 90th percentile $P(0.9)$ and the 10th percentile $P(0.1)$. SOURCE: RateWatch

Figure 2: The coefficient of variation



NOTE: The coefficient of variation is computed as the annual average of the ratio between the weekly cross-sectional standard deviation and mean for the selected maturities.
SOURCE: RateWatch

A *second* stylized fact that emerges from Figure (1) and Table (1) is that the yield dispersion is time varying and pro-cyclical with respect to the levels of the treasury yields. When the matched maturity treasury yields are increasing and high, the CD yield dispersion is also increasing and high. When interest rates are falling and low, the CD yield dispersion is quickly collapsing and low. The yield dispersion cyclicality differs across maturities. The positive correlation between the level of market interest rates and the price dispersion is decreasing with maturity. In 2003, when the level of interest rates was low the yield dispersion was increasing in the maturity of the contract. In 2007, the pattern reverses and shorter maturities display higher yield dispersion.

The pro-cyclicality of the price dispersion is directly a consequence of the *third* stylized fact on the pricing of insured time deposits. Although all the banks were subject to the same macro-economic variation in their cost of funds as measured by the level of the federal funds rate, the banks adjusted the yields on their time deposits rigidly and with little synchronization. Moreover, the *fourth* stylized fact is that the observed price rigidity and synchronicity of price adjustments among banks were asymmetric with respect to whether the fed funds rate was increasing, decreasing or remaining constant. Tables (2) and (3) document the distribution of the durations between price adjustments and the fraction of banks that adjust prices simultaneously over three distinct aggregate regimes - decreasing, constant and increasing level of the target fed funds rate.

Table 2: The duration in weeks between price adjustment

Fed Fund Target	decreased			unchanged			increased		
	p25	p50	p75	p25	p50	p75	p25	p50	p75
3-month	0	3	11	1	7	20	1	6	16
6-month	0	2	7	2	6	17	2	5	12
12-month	0	2	6	1	5	15	1	5	11
24-month	0	2	6	1	5	14	1	5	12
36-month	0	2	6	0	5	14	1	5	12
60-month	0	1	5	0	3	12	0	3	12

NOTE: The table computes the interquartile range of durations between price adjustments measured in weeks at the bank level for three regimes. The first regime is periods when the target fed funds rate was decreased, the second regime is periods when the target remained unchanged and the last regime includes periods when the target was increased. The sample period is 1-January-1997 - 30-June-2011.
SOURCE: RateWatch

Let us examine the 3-month contract. The 3-month retail deposit rates were sluggish to adjust when the fed funds rate was increasing with a median duration of price adjustments of 6 weeks during periods of increasing target fed funds rate. This was slightly lower than the 7 weeks during periods when the target fed funds remained unchanged. In contrast, when the target fed funds rate was decreasing, the median duration was 3 weeks. All maturities displayed the same asymmetric response to changes in the market rates. Longer maturities, however, exhibited more flexible price adjustment in all three regimes.

Table 3: The synchronization of price adjustments

Fed Fund Target	decreased			unchanged			increased		
	p25	p50	p75	p25	p50	p75	p25	p50	p75
3-month	0.13	0.20	0.28	0.08	0.11	0.13	0.10	0.12	0.14
6-month	0.16	0.26	0.36	0.09	0.13	0.16	0.12	0.14	0.16
12-month	0.18	0.27	0.36	0.11	0.14	0.17	0.13	0.14	0.17
24-month	0.16	0.25	0.36	0.10	0.13	0.16	0.12	0.13	0.14
36-month	0.15	0.24	0.36	0.09	0.12	0.15	0.10	0.12	0.13
60-month	0.15	0.24	0.34	0.09	0.11	0.14	0.09	0.11	0.12

NOTE: The table computes the interquartile range of the fraction of synchronized price changes. The latter is computed as the fraction of banks that adjusted their price in a given week. The summary statistics are computed for the three regimes of the target fed funds rate as in table (2). The sample period is 1-January-1997 - 30-June-2011.
SOURCE: RateWatch

The banks' price adjustments were not synchronized as documented in Table (3). Although each bank faced the same aggregate shock, changes in the fed funds rate, there was little synchronization in the yield adjustments. During periods of increasing fed funds target rate the median fraction of adjusters was around 12 percent, slightly higher than the 11 percent in periods of constant target. The fraction doubled to 20 percent during periods of decreasing fed funds target rate. Unlike the duration of price adjustments, there were no statistically significant differences in the measure of price synchronization across the different maturities.

2.2 The certificate of deposit market

The market for insured certificates of deposits or small time deposits is a relatively large and highly competitive market. In 2007, the total amount invested in small time deposits at commercial and savings banks was 1.25 trillion U.S. dollars. The market for close substitutes of the interest bearing components of the M2 aggregate excluding the M1 components amounted to 6 trillion U.S. dollars, of which 900 billion was invested in the retail money market funds. Although this period was characterized by considerable consolidation of the industry through mergers and acquisitions, the number of commercial banks exceeded 7,000 institutions and the actual average number of banks in a given state or metropolitan statistical area (MSA) increased as many banks expanded their operations in multiple states.

[10] This was also a period over which the advances in internet technology allowed for internet banking and price comparison websites both of which should have significantly reduced the transaction costs of acquiring information about the banks' offers, as well as reduced the costs of maintaining accounts at different institutions outside one's geographic market or one's main checking account bank thus creating a national market for deposits. U.S. households were also given an expanding set of investment possibilities that are close substitutes for time deposits. The increase in the available retail money market funds as well as the introduction of TreasuryDirect which granted individual investors access to the treasury market at a significantly low transaction cost have both further increased the competitive pressures that banks had faced for attracting the savings of US households. All these trends over the sample period make the documented stylized facts on the pricing of time deposits even more puzzling.

2.3 The characteristics of the CD contract

A treasury bond and a CD are both a fixed income instrument with a predetermined maturity. The standard maturities that banks offer for the CD contract are 3-months, 6-months, 1-year, 2-year, 3-year and 5-year. The contracts come in two main varieties - small denomination CDs for deposits below 100,000 dollars and large denomination CDs for deposits above 100,000 dollars. The hundred thousand dollar cut-off value distinguished insured from non-insured deposit accounts until October 3 2008 when the insurance limit was raised to 250,000.

Except for the shorter maturities offered, CDs differ from government bonds in terms of their taxation, liquidity and riskiness. Unlike government bonds, certificates of deposits are taxed both at the state and at the federal level. In terms of their price risk, CD contracts specify a pre-fixed interest rate for the term of the contract, thus, insuring the holder of the CD contract from future decreases in the market interest rates. Normally, CD contracts contain an early withdrawal penalty fee which makes them illiquid and risky if investors face liquidity shocks that would require them to withdraw from the contract before maturity. The CD contract is, thus, significantly less liquid than the corresponding treasury bond. [11]

The standard CD contract specifies the maturity, the interest rate, the minimum deposit requirement and the penalty fee for early withdrawal. Table (4) summarizes the distribution of the main contract characteristics for a survey of the ten largest banks in the ten largest deposit markets. For example, the median early withdrawal penalty fee for the 3-month

[10] The Riegle-Niel act of 1994 allowed banks to expand in multiple states and led to the creation of national banks which competed for deposits in multiple states throughout the nation.

[11] The amount lost in case of early withdrawal is pre-fixed and known at the time of the signing of the CD contract which could be valued if the investors prefer early resolution of uncertainty while in the case of a treasury bond the investor faces the price risk in case she sells the bond before maturity.

Table 4: The CD contract characteristics

		3-month	6-month	1-year	2.5-year	5-year
Min. deposit amount	median	1000	1000	1000	1000	1000
	mean	1642.35	1444.53	1325.50	1361.67	1795.41
	std	1959.57	1721.50	1490.28	1556.77	2430.28
Yield	median	2.86	3.75	4.00	3.90	4.07
	mean	2.88	3.59	3.81	3.80	4.06
	std	1.22	1.20	1.07	0.88	0.83
Penalty (days)	median	90	90	180	180	180
	mean	70.32	96.35	151.62	201.18	246.67
	std	27.91	37.87	58.14	76.75	157.86
		Spearman rank correlation				
Min.amount - yield	Rank corr.	-0.10	-0.01	0.02	-0.01	0.05
	p-value	0.35	0.93	0.85	0.94	0.63
Penalty (days) - yield	Rank corr.	-0.31	-0.15	-0.10	0.09	0.17
	p-value	0.00	0.15	0.31	0.41	0.11
Min.amount - penalty (days)	Rank corr.	0.03	0.00	-0.19	-0.21	-0.13
	p-value	0.77	0.99	0.07	0.06	0.22

NOTE: The table gives summary statistics for the minimum deposit, the yield and the penalty fees for a survey of the CD contracts offered by the 10 largest banks in the 10 largest deposit markets in the U.S. conducted by BankRate Monitor in 2006. The penalty fee is stated in days of accrued interest. The lower panel of the table contains the pair-wise Spearman rank correlations and the corresponding p-values using the Sidak correction.
SOURCE: BankRate Monitor

and the 6-month CD were worth 90 days and 180 days of interest, respectively. There was variation of the contract characteristics among banks. However, the variation in the non-price characteristics of the contract was not associated with the yield. The lower panel of the table gives the Spearman pairwise rank correlation between the three characteristics of the contract. The minimum amount correlated neither with the posted yield nor with the penalty fee for any of the maturities. The correlation between the penalty fee and the yield was statistically significant only for the 3-month CD contract. However, the negative correlation of -0.31 goes against the intuition that high penalty fee contracts should compensate for the reduced liquidity with a higher yield. The early withdrawal penalty fees are usually not explicitly advertised and remain a shrouded attribute of the contract.[12]

[12] Banks do not compete or publicly advertise the size of the penalty fees for early withdrawal of the certificate of deposit contract. This makes these attributes shrouded add-on costs of this financial product. See Gabaix and Laibson [2006] for further examples of product pricing in the presence of myopic consumers.

2.4 The participation in the CD market

Table (5) summarizes information from the 2007 Survey of Consumer Finances (SCF2007) on the participation rates of US households in five major categories of financial assets. Sixteen percent of households held a certificate of deposit which was comparable to the direct participation in the stock and treasury bond markets (savings bonds).

Table 5: The household participation rates in financial assets

	Transaction accounts	Certificates of deposit	Savings bonds	Bonds	Stocks	Any financial asset
Participation rate	92.1	16.1	14.9	1.6	17.9	93.9

SOURCE: Survey of Consumer Finance, 2007

Table (5) shows that the participation in the CD market and the absolute amount invested increase with age, income and net-worth. More than one quarter of households in retirement age owned a CD with median investment exceeding twenty thousand. [13]

Table 6: The participation in the CD market by household characteristics

			Age groups			
Less than	35	35 – 44	45 – 54	55 – 64	65 – 74	75 or more
Participation	6.7	9.0	14.3	20.5	24.2	37.0
Median amount	5.0	5.0	15.0	23.0	23.2	30.0
			Income percentiles			
Less than	20	20 – 39.9	40 – 59.9	60 – 79.9	80 – 89.9	90 – 100
Participation	3.6	8.5	15.2	20.9	26.2	26.1
Median amount	18.0	18.0	17.0	11.0	20.0	42.0
			Net-worth percentiles			
Less than	25	25 – 49.9	50 – 74.9	75 – 89.9	90 – 100	
Participation	2.5	9.9	19.4	32.5	32.9	
Median amount	2.0	7.0	15.0	25.0	50.0	

SOURCE: Median amounts are in thousands.
Survey of Consumer Finance, 2007

The important question is whether there is direct or indirect evidence that investors in this market actively searched for the best yield on their savings or rather they were

[13]See Becker [2007] documents that MSA areas with larger share of the population comprised of senior households are also areas with larger deposit markets.

locked into a long-term relationship with their main bank. Studies have uncovered the presence of large switching costs in the market for transaction deposit accounts such as checking accounts and interest bearing savings accounts [14]. The presence of large switching costs could explain the large median duration of checking account relationships reported in SCF2007 as 20 years. Further, when it comes to transaction accounts, attributes such as the closeness of bank's offices and the density of its branch and ATM networks bring valuable convenience and should determine the choice of one bank over the other.

Regarding time deposits, however, the convenience of branch and ATM networks matters considerably less, especially with the advent of internet banking. Moreover, by their nature, CD contract relationships have a pre-determined maturity and need to be re-established after the maturity of the contract expires. Due to the relative illiquidity of the CD investment in the presence of early withdrawal penalties and the upward sloping yield curve, a commonly recommended investment strategy that optimizes the trade-off between the liquidity risk and the higher yield in longer maturity contracts is the so called "CD ladder" which requires an investor to first search for the best yield and then allocate her investment in multiple maturity CDs. [15] A further reason for investors to shop around for CDs in different institutions from their main checking account bank is that the FDIC insurance limit applies to accounts with one institution for each depositor [16]. The existence of over 7,000 commercial bank institutions subject to FDIC insurance makes it possible to insure against credit risk large investments by distributing these investments over a large set of institutions.

Table (7) gives summary statistics on the number of CDs, the average amount invested and the number of institutions where these CD contracts are held with. The median amount invested in a CD is 10,000 with half of the investors holding at least 2 CD contracts.

[14] Sharpe [1997] identifies switching costs using the share of migrating customers among geographically segmented markets. Hannan and Adams [2011] for a more recent estimation. These studies do not directly estimate the magnitude of the switching costs but rather uncover a statistically significant positive effect of in-migration into an MSA area and the level of interest rates offered by the banks in the area.

[15] Financial advisory websites such as BankRate.com and DepositsAccount.com recommend that savers shop around for best yields and warn that there is large existing price dispersion in the contracts. An example is a recent article on Bank Rate Monitor with advice on investing in the CD market http://www.bankrate.com/finance/exclusives/online-or-branch-where-is-the-best-yield--1.aspx

[16] FDIC allows the insurance coverage to be extended to joint account ownership to potentially cover amounts up to 3,000,000 for a single institution. See http://www.fdic.gov/deposit/ Additionally, the Certificate of Deposit Account Registry Service is a for-profit service that allows individuals to FDIC insure large investments by distributing these investments among multiple banks saving on the transaction costs of opening and maintaining multiple accounts with multiple banks.

Table 7: The summary statistics of the CD contract holdings

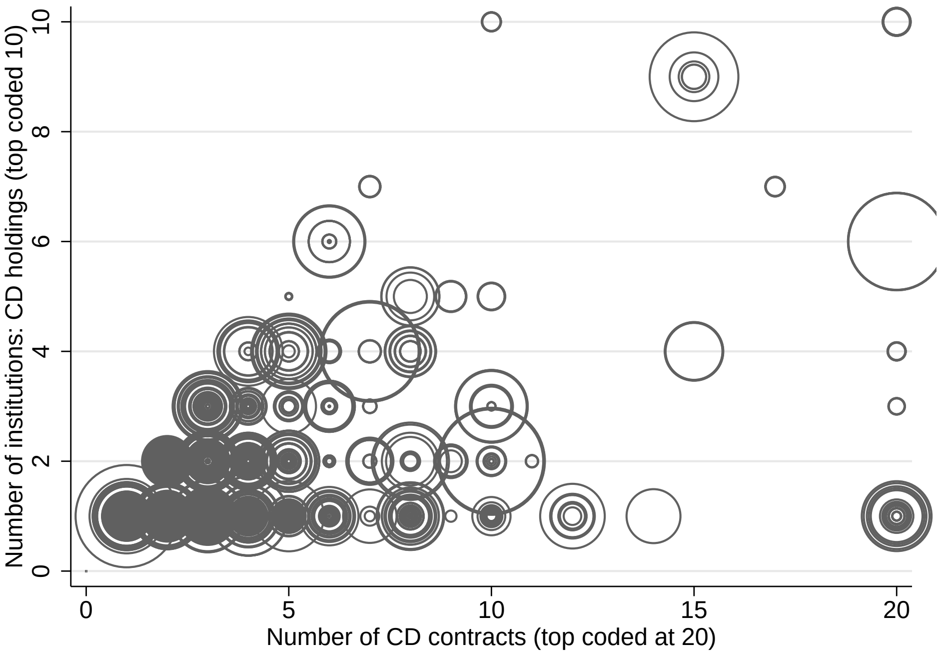
	mean	min	p5	p25	p50	p75	p95	max
Number CDs	2.40	1	1	1	2	3	6	20
Number institutions	1.28	1	1	1	1	1	3	10
CD amount total	55,630.86	50	1,000	5,800	20,000	51,000	200,000	47,000,000
CD amount per contract	24,083.64	50	1,000	4,000	10,000	25,000	100,000	16,000,000

NOTE: The number of CDs and institutions are top-coded in the public dataset at 20 and 10, respectively. The statistics are computed using the weights provided by SCF 2007.
SOURCE: Survey of Consumer Finance, 2007

While a large fraction of the investors hold CDs with only one institution, it is not necessary the same financial institution they have a checking account. SCF 2007 reports that 45 % of investors had a CD account with an institution different from their main checking account institution. Figure (3) presents the scatter plot of the number of CD contracts and the number of institutions these contracts are held with weighted by the amount invested represented by the size of the circle. There is a clear positive relationship between the number of CD contracts and the number of distinct banks where these contracts are held with. The correlation coefficient between the two is 0.75. The total amount of the investment in CDs is weakly positively correlated with the number of institutions with a correlation coefficient of 0.25. This weak correlation tells us that the reason for holding CDs in multiple institutions is not entirely driven by the FDIC insurance motive. The patterns in Figure (3) provide some indirect evidence that the investors in this market did invest in multiple institutions and while doing so searched for the best return on their investment. These patterns observed in the SCF dataset are consistent with the findings from the estimated structural model which I discuss in Section (4.1).

While encouraging, this indirect evidence is insufficient to rule out completely the effect of switching costs and bundling as a source of the monopoly power of a bank in the market for time deposits both for its existing and for its new depositors. However, in order to measure the effects of these one needs a more detailed transactions data. A somewhat lower bound on the magnitude of the switching costs could be computed from the penalty fees for early withdrawal given in Table (4). For the investors who already hold a CD with a bank moving their time deposit savings to a different bank would mean paying this penalty fee. For the one year contract, for example, the penalty fee for early withdrawal is 180 days or half a year worth of interest. In 2006, the median yield on the one year contract was 381 basis points. Thus, an investor who invested in the one year contract in 2006 would be locked into the contract and face a cost of at least 190 basis points to withdraw her investment and switch to a different institution. For the rest of the analysis,

Figure 3: The number of contracts and number of institutions



NOTE: The scatter plot weights the observations by the total amount invested in CD contracts. A larger circle means a larger amount invested. The number of CD contracts and the number of institutions are top coded at 20 and 10, respectively. SOURCE: Survey of Consumer Finances, 2007

we will focus on identifying the information costs faced by the depositors who are making new investments and do not face these penalty fees.

The final indirect evidence that investors in the market for insured CDs responded to price information and that banks competed in prices is the deposit rate dataset itself. The RateWatch survey data[17] contains only price information on active offers that banks publicly made to both their existing customers but also to the general public and does not contain any additional information on bundling with other services provided by the bank. The same price information as in the dataset was what investors would have obtained if they had made Internet search on rate comparison websites such as BankRate.com or Google-Finance, or if they had visited directly a branch of a bank or its website. The competition in the market for CDs was competition in prices at least as measured by the available data.

[17]See the Appendix for details

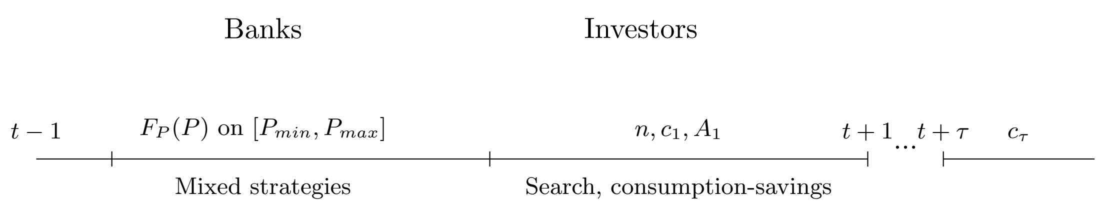
3 Model

A unit mass of investors conduct costly search for the best return on their τ-period investment. The investors are heterogeneous with respect to their search cost and financial wealth. The marginal distribution of search costs is given by the cdf $F_\xi(\xi)$ and the marginal distribution of financial wealth is given by the cdf $F_\omega(\omega)$.

There is $1/N$ measure of retail banks per investor which offer time deposit contracts insured by the government. The deposit insurance rules out bank runs as in Diamond and Dybvig [1983]. In case of a bank failure, the deposit insurance fund would credibly cover the whole amount of the deposit contract obligation including the interest. As a result of the deposit insurance, the bank characteristics are irrelevant in the pricing of the insured deposit contract and the insured deposits are treated as a homogeneous financial product by the investors.

The banks compete in prices facing a common marginal cost $\tilde{P}$ [18]. In order to sustain equilibrium price dispersion and extract monopoly profits, the banks rely on the ex-post asymmetric information investors have about the position of the best offers due to the costly search to obtain this information. The banks play symmetric mixed strategies which lead to an equilibrium price distribution of deposit offers $F_P(P)$ on a finite support $[P_{min}, P_{max}]$. In equilibrium, each bank is indifferent between posting any price in the support of the distribution and earns a strictly positive monopoly profit.

Figure 4: Time-line of events



The model can be summarized as the sub-game perfect equilibrium where the banks first play mixed strategies equilibrium in the pricing of the deposit contracts, anticipating the optimal search and consumption-savings decisions of the investors. Given this offer distribution, the investors decide whether and how intensely to search for the best deposit offer or choose to invest in the risky asset. Once the search phase is complete, each investor makes a consumption-savings decision based on the rate of return she has available.

[18] I define prices as the inverse of the gross rate of return $P = 1/R$

3.1 The investor problem

Each period t a unit mass of investors enters the market for time deposits. The investors are interested in transferring wealth over this period of time to satisfy consumption at period τ and do not consider any interim income, consumption or the possibility to reinvest in a different asset. The investor maximizes utility which takes the following form:

$$u_\tau(c_1, c_\tau) = \begin{cases} \left\{c_1^{1-\frac{1}{\sigma}} + \beta^\tau([E(c_\tau^{1-\gamma})]^{\frac{1}{1-\gamma}})^{(1-\frac{1}{\sigma})}\right\}^{\frac{\sigma}{\sigma-1}} & \text{if } \sigma \neq 1 \\ lnc_1 + \beta^\tau ln[Ec_\tau^{1-\gamma}]^{\frac{1}{1-\gamma}} & \text{if } \sigma = 1 \end{cases} \tag{1}$$

This specification allows for the separation of risk-aversion $\gamma > 0$ and the inter-temporal elasticity of substitution $\sigma > 0$. If an investor invests in the risky asset, her end-period wealth and consumption are stochastic. The investor is risk-averse and the term $\mu(c_\tau) = ([E(c_\tau^{1-\gamma})]^{\frac{1}{1-\gamma}})$ measures the certainty equivalent of the risky-asset lottery.

At the beginning of the period the investor has initial endowment $\omega = (\omega_0, \omega_1)$. The first component of which ω_0 is used during the search stage and can be thought of as the amount of available time to allocate between leisure and costly search while ω_1 is the financial wealth that the investor considers for investment. The cross-sectional distribution of posted deposit offers $F_P(P)$ and the distribution of final pay-offs of the risky asset $\Phi(P^r)$ are public information.

Initially, the investor decides whether to invest in the deposit contract or in the risky asset. If she decides to invest in the deposit contract, she goes through a costly search stage during which she makes a decision on how many bank offers to sample n and considers the lowest price. The search is costly as the investor incurs an idiosyncratic cost ξ per search. After the search stage the investor can either accept the best offer from the sample of offers she has or she still has the option to invest in the risky asset. If in the initial stage, she decides to invest in the risky asset, she saves on the costly search effort and expends the time endowment for leisure consumption $c_0 = \omega_0$. The investor does not have stochastic income in the future period and hence she doesn't have hedging demand and would always choose the asset that gives her the lowest risk-adjusted price of future consumption. Whichever investment option she chooses, in the consumption-savings stage she decides on how much to consume today c_1 versus how much to invest for future consumption c_τ given the best price of future consumption she has available.

It is important to note the temporal nature of the resolution of uncertainty of the two types of saving vehicles. If the investor decides to conduct costly search and invest in a deposit contract, she faces the uncertainty of the cross-sectional distribution of deposit offers. By increasing her search effort, she can reduce the uncertainty about the best offer she can obtain. The uncertainty of the final pay-off for the deposit contract is resolved after the costly search. If the investor invests in the risky asset, the uncertainty is only resolved as the final pay-off is realized. The investor does not have control over this return.

3.1.1 The consumption-savings decision

At the consumption savings stage, households have already made a decision on what type of asset to invest in and face an expected price at which they can substitute consumption over time. Given this price or yield, they decide how much to deposit and how much to consume today.

$$\nu_\tau(P^i_\tau, \omega_1) = max_{c_1, c_\tau, A_\tau} u_\tau(c_1, c_\tau), i \in \{d, r\} \tag{2}$$

$$\begin{aligned} &\text{subject to:} \\ &c_1 + A_\tau = \omega_1 \\ &c_\tau = R^i_\tau A_\tau \\ &c_1 \geq 0, A_\tau \geq 0 \end{aligned} \tag{3}$$

For analytical convenience, I assume that the risky asset holding period return over τ-periods is distributed log-normally $lnR^r_\tau \sim_d N(ln\bar{R}^r - \frac{1}{2}\sigma^2_r, \sigma^2_r)$.[19] I summarize the solution to the consumption savings problem in the following proposition.

Proposition 1 *The solution of the consumption-savings problem (2) is well-defined and takes the following form:*

$$c^i_1 = h^i_\tau(P^i) \times \omega_1 \tag{4}$$

$$c^i_\tau = \frac{1}{P^i}(1 - h^i_\tau(P^i)) \times \omega_1 \tag{5}$$

$$A^i_\tau = (1 - h^i_\tau(P^i)) \times \omega_1 \tag{6}$$

The marginal propensity to consume out of wealth for $\sigma \neq 1$ takes the following functional

[19]The term $-\frac{1}{2}\sigma^2_r$ corrects for the Jensen's inequality and makes the parameter σ_r measure the mean preserving spread. The implicit price of τ-period consumption using the risky asset is distributed also log-normally $lnP^r \sim_d N(ln\bar{P}^r + \frac{1}{2}\sigma^2_r, \sigma^2_r)$ and the expected price is $\bar{P}^r = \frac{1}{\bar{R}^r}$.

form for deposits and risky assets:

$$h^d_\tau(P^d) = \frac{1}{1+\beta^{\tau\sigma} {P^d}^{1-\sigma}} \quad (7)$$

$$h^r_\tau(P^r)) = \frac{1}{1+\beta^{\tau\sigma}\left[E(P^r)e^{\frac{\gamma}{2}\sigma_r^2}\right]^{1-\sigma}} \quad (8)$$

The indirect utility is linear in financial wealth:

$$\nu(P^i, \omega_1) = \phi^i_\tau(P^i)w_1 \quad (9)$$

where the marginal utility of wealth $\phi^i_\tau(P) = h^i_\tau(P)^{\frac{1}{1-\sigma}}$ *is a decreasing and convex function of the expected price i.e.* $\phi'_\tau(\cdot) < 0$ *and* $\phi''_\tau(\cdot) > 0$*. In the case where* $\sigma = 1$*, the marginal propensity to consume is constant* $h_\tau(P^i) = \frac{1}{1+\beta^\tau}$*.*

Proof The results are straightforward to show and rely on the homogeneity of degree one of the utility function and log-normality of the return on the risky asset.□

If the inter-temporal elasticity of substitution exceeds 1, then the substitution effect dominates over the income effect and the marginal propensity to save is decreasing in P. Conversely, if $\sigma < 1$ investors prefer smooth consumption profiles and in this case the marginal propensity to save is increasing in P. Unlike the deposit contract, the marginal propensity to consume for the risky asset contains a risk-adjustment factor $e^{\frac{1}{2}\gamma\sigma_r^2}$ which is a function of the coefficient of relative risk-aversion γ and the volatility of the asset return σ_r. Higher volatility of the pay-off of the risky asset increases the risk-adjusted price.

3.1.2 Non-sequential search

At the search stage the investor faces the task of finding information about what specific rates of return banks offer on deposits. The only public information at this stage is the equilibrium distribution of deposit offers ${F^d}_P(P)$. Although the investors are aware of the aggregate distribution of offers, they have no prior information about the specific rate each bank posted.[20] Information gathering is costly as each investor faces an idiosyncratic search cost ξ per search which is proportional to her financial wealth [21]. Her total search cost is linear in the number n quotes $(n-1)\times\xi$. The first sample point is costless which ensures that there is participation in the deposit market even for investors with high search costs [22]. If an investor decides on a random sample of size n, then she picks the offer with

[20]The assumption that the investor knows the distribution of offers is rather strong. Rothschild [1974] relaxes this assumption introduces learning about the price distribution in a model of costly search.

[21]The assumption is that the opportunity cost of time increases linearly with financial wealth.

[22]One can think of this assumption as follows. Each investor has a checking account with a bank and can costlessly observe the price posted by this bank on its time deposits.

the lowest price or highest rate of return. The cumulative distribution function of this minimal price is $P_{min}(n) \equiv min\{P_1, .., P_n\} \sim_d 1 - (1 - F_P(P))^n$ and the corresponding pdf is $n(1 - F_P(P))^{n-1} f_P(P)$. [23]

In the search stage the investor has ω_0 endowment of time which she uses for search. The problem of the investor at the search stage is to maximize expected utility by choosing the optimal sample size n while satisfying the budget constraint $\omega_0 - (n-1) \times \xi \geq 0$.

$$V(\xi) = \max_{n \in \mathbb{N}} \Big\{ \omega_0 - (n-1) \times \xi + \int_{P_{min}}^{P_{max}} \phi(P) n (1 - F_P(P))^{n-1} f_P(P) dP \Big\} \tag{10}$$

The quasi-linear utility assumption is chosen for analytical convenience but it also gives an alternative interpretation of the search cost as the dis-utility of the time spent searching for the best return. To solve the problem, let us define the extra utility gained from increasing the sample size by one extra offer given that the investor has already sampled n offers:

$$\Delta_n = \int_{P_{min}}^{P_{max}} \phi(P)(1 - F_P(P))^{n-1} \Big\{ 1 - (n+1) F_P(P)^n \Big\} f_P(P) dP \tag{11}$$

The set $\{\Delta_n\}_{n=1}^N$ defines a set of indifference points where an investor with search cost $\xi = \Delta_n$ is indifferent between drawing a sample of offers size n or $n+1$. The incentives to search are determined by the trade-off between paying the search cost on one hand and both obtaining a higher expected rate of return but also reducing the uncertainty about the return on the investment. Both the mean and the variance of $P_{min}(n)$ are decreasing in n. The marginal utility of wealth $\phi^d(P)$ is decreasing and convex in P. This implies that higher price dispersion increases the marginal utility of wealth and the option to search. The inter-temporal elasticity of substitution determines the degree of convexity and hence the incentives to search.

Proposition 2 *The optimal non-sequential search problem can be defined as:*

$$n^*(\xi) = argmax_{n \in \mathbb{N}} \Big\{ \Delta_n s.t. \Delta_n \geq \xi \Big\} \tag{12}$$

The problem is well defined and has a unique solution. For any atomless deposit offer distribution $F_P(P)$ and underlying distribution of cost types $F_\xi(\xi)$, the equilibrium search can

[23] The assumption of non-sequential search could be justified by the presence of economies of scale of search. Also recent evidence in De los Santos, Hortacsu, and Wildenbeest [2012] shows that the non-sequential fixed sample search model better describes actual search behavior. Morgan and Manning [1985] derive conditions under which different modes of search are optimal.

be summarized as the segments of investors with different search intensity and a common reservation price $\left(\{q_k\}_{k=1}^N, \dot{P}_\tau\right)$. *Investors of measure* q_N *with search costs* $\xi < \Delta_{N-1}$ *search for* N *prices and incur a total search cost* $(N-1)\xi$, q_k *investors with search costs* $\Delta_k < \xi < \Delta_{k-1}$ *search* k *deposit offers. The investors with the highest search cost* $\xi > \Delta_1$ *only observe one offer and form* q_1 *fraction of the population.*

Proof By simple differentiation it can be easily shown that Δ_n is non-increasing and convex in n. The rest of the results are shown in the paragraphs below. □

Investors in this market are heterogeneous with respect to their search costs. The individual search cost is drawn from a known population distribution $F_\xi(\xi)$ with support on $\mathbb{R}^+$. According to the optimal search rule $n^*(\xi) : \mathbb{R}^+ \to \mathbb{N}$, the investors are divided in distinct segments according to the optimal sample size they choose to search. The set $\{q_k\}_{k=1}^N$ defines the fractions of the population of investors determined by the optimal sample size they choose to search $k = 1, 2, .., N$. These fractions are defined as follows.

$$\begin{aligned} q_1 &= 1 - F_\xi(\Delta_1) \\ &\vdots \\ q_k &= F_\xi(\Delta_{k-1}) - F_\xi(\Delta_k) \\ &\vdots \\ q_N &= 1 - \sum_{j=1}^{N-1} q_j \end{aligned} \tag{13}$$

Each segment faces an offer distribution according to the distribution of the minimal price - $\{P_{min}(k)\}_{k=1}^N$.

Once incurred search costs are sunk and households can always choose not to invest in a time deposit if the best rate of return they obtained after the costly search stage is dominated by the risky asset return. A reservation price (yield) determines the highest price (lowest yield) that a household is willing to accept.

Lemma 1 *The reservation price and the choice to participate in a deposit contract do not depend on the individual search cost. The reservation price is*

$$\dot{P} = EP^r \times e^{\frac{\gamma}{2} \times \sigma_r^2} \tag{14}$$

Proof The results follow from the linearity in wealth of the indirect utility and the zero cost of observing one deposit offer. Ex-ante participation requires that the value of searching and investing in a deposit contract exceeds the outside option of directly investing in the risky asset. The outside option of the investor is determined by the value of investing in the risky asset $V^r(P^r) = \omega_0 + \phi^r(P)\omega_1$. Let $V_1^d = \omega_0 + \omega_1 \int_{P_{min}}^{P_{max}} \phi^d(P) f_P(P) dP$ be the value of participating in the deposit contract with the restriction that the investor draws only one costless sample offer. This value is always dominated by the value of optimal search $V^d(\xi)$ and the condition for ex-ante participation in the deposit market can be written as $V^d(\xi) \geq V_1^d \geq V^r(P_\tau^r)$ where the second inequality matters for ex-ante participation. The ex-ante participation in the market does not depend on the individual search cost ξ. The ex-post participation in a deposit contract is guaranteed if any deposit offer which is the result of optimal search is preferred to investing in the risky asset $\forall P^d \in \mathcal{S}: \ \phi^d(P^d) \geq \phi^r(P^r)$. It is obvious that if ex-post participation is satisfied, so is ex-ante participation. The reservation price is, therefore, defined as the maximum price that an investor would be willing to accept given her outside option to invest in the risky asset.

$$\dot{P}^d = sup_x\{\phi^d(x) \geq \phi^r(P^r)\} \tag{15}$$

Since the marginal utility of wealth $\phi^d(P^d)$ is a decreasing function, the reservation price is uniquely defined. The important property of the reservation price is that it doesn't depend on the idiosyncratic search cost and is common to all investors. □

The reservation price is a function of the expected price for the risky asset and the risk-adjustment factor. Taking logs of the expression for the reservation price to define yields, I can express the reservation price in terms of risk-premium spread $\bar{s}^{r-d} = y^r - y^d = \frac{\gamma}{2} \times \sigma_r^2$. In the rational expectations equilibrium defined below, the reservation price defines the upper bound on the price distribution $P_{max} \leq \dot{P}$ as no investor would participate in the deposit market if the deposit price exceeds the reservation price.

3.2 The banks' problem of deposit pricing

The banks operate in local loan and deposit markets. A bank maximizes per period profits by choosing its assets and its funding sources. On the asset side the banks lend funds to borrowers at a rate determined by a loan demand function $L_t = g^L(R_t^l)$ and hold required reserves which earn a rate of return R_t^s. The banks fund their activities with insured retail deposits D_t and non-insured wholesale funding B_t. Both the rate of return on reserves R_t^s and the cost of funds from wholesale funding R_t^b (the fed funds market, for example) are determined exogenously by the monetary authority. Insured deposits are subject to reserve requirement $\alpha \in (0, 1)$ per unit of insured deposits and the banks have no incentive to hold excess reserves. As a result, all the reserves held by the banks are to satisfy the required reserve requirement - $S_t = \alpha D_t$. The banks face a downward sloping demand curve for deposits $D_t = g^D(R_t^d)$. The lending and funding problem of the bank is summarized as:

$$\pi_t = \max_{R_t^l, S_t, R_t^d, B_t} \left\{ R_t^l L_t + R_t^s S_t - R_t^b B_t - R_t^d D_t \right\} \tag{16}$$
$$subject\ to:$$
$$S_t + L_t = B_t + D_t$$
$$S_t = \alpha D_t$$

Substituting the budget constraint and the reserve requirement, the static profit function of the bank can be decomposed into two separate profit centers.

$$\pi = \max_{R^l} \left\{ (R^l - \tilde{R}) g^L(R^l) \right\} + \max_{R^d} \left\{ (\tilde{R} - R^d) g^D(R^d) \right\} = \pi^l + \pi^d \tag{17}$$

The banking profit maximization problem can, thus, be written as two separate profit optimization problems. For the purposes of this paper this separation is convenient and allows us to focus on the problem of choosing the deposit interest rate policy independently from the lending activity. The marginal cost of funds for the bank $\tilde{R}$ is defined as the weighted average of the interest on reserves and the cost of wholesale funding with a weight equal to the required reserves ratio α.

$$\tilde{R} = \alpha R^s + (1 - \alpha) R^b \tag{18}$$

This opportunity cost is assumed exogenously determined by the interest rate policies of the monetary authority and common to all banks.

Banks take as given the optimal search and consumption-savings decision of households when competing for insured deposits. Suppose that a bank posts a price within the support of the equilibrium price distribution $P^d \in \mathcal{S} \equiv [P^d_{min}, P^d_{max}]$. Investors who sampled k offers would choose this particular bank if this is their best offer in their sample. This event occurs with probability $k(1 - F_P(P^d))^{k-1}$. The share of investors who sampled k banks is q_k. The mass of investors the bank would expect to attract is $\frac{1}{N} \sum_{k=1}^{N} q_k k (1 - F_p(P^d))^{k-1}$. An investor with financial wealth ω_1 would invest $(1 - h^d(P^d))\omega_1$ in the deposit contract. Integrating the financial wealth of investors in the market W, the deposit demand function faced by each bank is $g^D(P^d) = (1 - h^d(P^d)) W \frac{1}{N} \sum_{k=1}^{N} q_k k (1 - F_p(P^d_j))^{k-1}$. It can be shown that the demand function is downward sloping.

The expected profit that bank j would generate from posting price P_j^d is $\pi^d(P_j^d) = (P_j^d - \tilde{P})(1 - h^d(P_j^d))\frac{1}{N}\sum_{k=1}^{N} q_k k(1 - F_p(P_j^d))^{k-1}$. The first component is the profit per captured investor $\psi(P^d) = (P_j^d - \tilde{P})(1 - h^d(P_j^d))$ and the remainder is the size of the captured investor base.

The banks compete in prices and follow symmetric mixed strategies. In equilibrium bank j is indifferent between posting any price along the support of the equilibrium strategy $F_P(P)$ as it earns the same expected profit $\pi^d(P^d| \ F_P(P^d)) = \pi^{d*}$. Any price outside the support $\mathcal{S}$ of the equilibrium earns strictly lower profit.

Let P_m^d be the monopolistic price that maximizes the profits per captured investor $P_m^d = argmax_P \psi(P)$. The upper bound of the support of the price distribution is the lowest between this monopoly price and the reservation price of the investors in the market $P_{max}^d = min\{\dot{P}, P_m^d\}$. A bank would not post a price exceeding either the monopolistic price or the reservation price of the investors in the market. I summarize the full participation equilibrium in the deposit posting game as follows.

Definition *A symmetric Nash equilibrium in mixed strategies* in the deposit posting game *with full participation* is a deposit offer distribution $F_P(P^d)$ on the support $\mathcal{S}$ defined by a maximum price $P_{max} = min\{\dot{P}, P_m^d\}$ and minimum price P_{min} which are consistent with the optimal search and consumption-savings behavior of investors $\left(\{q_k\}_{k=1}^N, \dot{P}, h^d(P)\right)$. The equilibrium profit is constant over the equilibrium price support and strictly lower outside the price support.

$$\pi^d(P^d \mid F_P(P^d)) = \begin{cases} \psi(P^d)\left(\frac{1}{N}\sum_{k=1}^{N} q_k k(1 - F_p(P^d))^{k-1}\right) = \pi^{d*} & \text{if } P^d \in \mathcal{S} \\ < \pi^{d*} & \text{if } P^d \notin \mathcal{S} \end{cases} \tag{19}$$

In order to sustain equal profits along the support of the price distribution, the following trade-off is at work. A higher price generates a higher profit per captured investor $\psi(P)$ but attracts less investors. The two effects exactly offset each other along the support of the equilibrium price distribution. Even if the bank posts the lowest price, it still does not obtain the largest share in the market as only a fraction of the population samples its price. Similarly, a bank that posts the maximum price P_{max}, still attracts investors - the investors who sample only once and happen to be unlucky and obtain this price as their only sample point. No bank would offer a price outside the equilibrium price support as this would lead to a strictly lower profit.

Lemma 2 *The minimum price that a bank would post which defines the lower support of the price distribution is implicitly defined as:*

$$\psi(P_{min}) = \psi(P_{max})\frac{q_1}{\sum_{k=1}^{N} kq_k} \tag{20}$$

Proof Using the indifference condition (19) for the lowest and the highest price $\pi^d(P_{min}) = \pi^d(P_{max})$, one can solve for P_{min}. Unique solution is guaranteed as the banks would always operate on the increasing portion of $\psi(P)$. $\square$.

Examining (20), minimum price always exceeds the marginal cost of supplying deposits. As a result the banks are making positive profits in equilibrium $\pi^{d^*} > 0$. The banks effectively exploit a mark-up over marginal cost along the price support of the offer distribution. The ratio of the mark-ups for the lowest and the highest price of the equilibrium price distribution can be decomposed in two terms. An extensive margin mark-up which depends on the relative share of high information cost investors q_1 and an intensive margin which is related to the elasticity of the marginal propensity to save at the two extremes of the price distribution.

$$(P_{min} - \tilde{P})/(P_{max} - \tilde{P}) = \underbrace{\frac{q_1}{\sum_{k=1}^{N} kq_k}}_{\textit{Extensive margin}} \times \underbrace{\frac{(1 - h^d(P_{max}))}{(1 - h^d(P_{min}))}}_{\textit{Intensive margin}} \tag{21}$$

If the share of high information cost investors is equal to one $q_1 = 1$, then the price offer distribution is degenerate at the monopoly price P_{max} and the banks earn the monopoly profit $\pi^{d,M}$. This is consistent with the "Diamond paradox" (see Diamond [1971]). If all investors have high enough search costs so that everyone observes only one yield, the banks can sustain the monopoly price equilibrium. On the other extreme, if the share of the least informed agents is zero $q_1 = 0$, then each investor observes at least two yields. In this environment a bank competes in prices with at least one more bank and hence the Bertrand equilibrium is sustained. The price offer distribution is degenerate at the perfectly competitive price $\tilde{P}$ and the banks earn zero economic profits.

When the search cost distribution is such that $q_1 \in (0, 1)$ and a dispersed equilibrium exists where the equilibrium profits are between these two extremes $0 < \pi^{d^*} < \pi^{d,M}$. Unlike Burdett and Judd [1983], however, the search cost heterogeneity leads to a unique dispersed equilibrium. The following section characterizes the non-degenerate price equilibrium.

3.3 The equilibrium

The sub-game perfect equilibrium in the market for insured deposits is defined as the solution to the search and the consumption and savings problem of the investors as well as the deposit posting mixed strategies equilibrium of the banks.

Definition The set $\left(F_P(P), P_{min}, P_{max}, \pi^{d^*}, \{q_k\}_{k=1}^N, \dot{P}, h(P)\right)$ is the *market equilibrium with non-sequential search and full participation* if for a given distribution of investor types

$F_\xi(\xi)$ and distribution of future pay-offs of the alternative risky asset $\Phi(P^r)$:

a) $\left(\{q_k\}_{k=1}^N, \dot{P}, h(P)\right)$ is a solution to the optimal consumption savings and search problems of the investors given the distribution of deposit offer prices $F_P(P)$ and the endowment of the investors ω.

b) $\left(F_P(P), P_{min}, P_{max}, \pi^{d^*}\right)$ is a deposit pricing equilibrium with full ex-ante participation $P_{max} = min\{\dot{P}, P^m\}$ given the optimal consumption-savings and non-sequential search summarized by $\left(\{q_k\}_{k=1}^N, \dot{P}, h(P)\right)$

The equilibrium price distribution is continuous and with a connected support for a set of mild assumptions on the search cost distribution.

Proposition 3 *Given a sufficient mass of investors with high enough search costs such that $F_\xi(\Delta_1) > 0$ or $q_1 \in (0,1)$, there exists a unique non-degenerate equilibrium price distribution of deposit offers $F_P(P)$ implicitly defined in (19). $F_P(P)$ is continuous with connected support $\mathcal{S} = [P_{min}, P_{max}]$.*

Proof *The results follow from slight modification of arguments in Burdett and Judd [1983] and Moraga-Gonzalez, Sandor, and Wildenbeest [2010].* □

The results of proposition (3) guarantee that the model is identified and estimable using only the empirical price distribution.

3.4 Dynamic price adjustment

Having defined an equilibrium with price dispersion, we next examine the question whether the price rigidity and the asymmetric price adjustment observed in the pricing of the insured certificates of deposits could be also the result of the information constraints faced by the investors in this market. I extend the static model by solving for dynamics as a sequence of static problems in which aggregate shocks impact the support of the price distribution but do not alter the search strategy of the investors. The underlying assumption is that each period a new cohort of investors enters the market and there is no communication between consecutive cohorts of investors regarding the position of the best offers among the banks.

An important aggregate shock are changes in the marginal cost of funds induced by monetary policy. Suppose that monetary policy controls directly the marginal cost $\tilde{R}$ using an interest rate rule of the form $ln\tilde{R}_{t+1} = ln\mu^{\pm} + ln\tilde{R}_t$ where $\mu^+ = 1 + \kappa^+ > 1$ and $\mu^- = 1 - \kappa^- < 1$ measure the size of the step when interest rates are increased or decreased, respectively. [24]

[24] Since 1994 the Federal Reserve has adopted operating procedures that change the target fed funds rate on the day of FOMC meeting and the size of the changes are in multiples of 25 bps. See Piazzesi [2005] for analysis of the implications of the operating procedures of the Federal Open Market Committee for the term structure of interest rates.

During monetary policy tightening the marginal cost of funds is increased in a sequence of fed fund rate hikes over T^+ periods. Similarly, monetary policy easing reduces interest rates and the marginal cost of funds in a sequence of interest rate reductions over T^- periods. The third regime of monetary policy is to keep interest rates constant for T_0 periods.

Changes in aggregate conditions affect the equilibrium price support by changing the marginal cost of funds of the banks or the reservation yield of the investors. the banks which posted prices in the overlapping region of the t-period equilibrium support and the new equilibrium support $\mathcal{Z}_{t+1} = \mathcal{S}_{t+1} \bigcap \mathcal{S}_t$ have no extra incentive to reprice in period $t+1$, since repricing would not change their profits. The equilibrium profits change to a new equilibrium level ${\pi^d_{t+1}}^*$ but within the new price support any price gives the same expected profit allowing a fraction of the banks with prices set in previous periods which are still part of the new price support to keep these prices unchanged.

In order to sustain the equilibrium in period $t+1$, the repricing strategies must lead to a new price distribution consistent with the equilibrium defined in the previous section. The set of these repricing strategies is called admissible.

Definition A repricing policy $P^*_{t+1}(P)$ given an equilibrium price distribution $F_{P,t}(P)$ in period t is *admissible*, if, given that all the banks follow this strategy after a change in aggregate conditions, the resulting distribution in period $t+1$ is an equilibrium distribution $F_{P,t+1}(P)$ where the new equilibrium is defined as in section (3.3).

Although there are multiple admissible repricing strategies, I examine the following symmetric strategy following Head, Liu, Menzio, and Wright [2012].

$$P^*_{t+1}(P,\rho) = \begin{cases} P' & \text{if } P \notin \mathcal{S}_{t+1} \\ \{P, P'\} \text{ with prob.}(\rho, 1-\rho) & \text{if } P \in \mathcal{S}_{t+1} \\ & P' \sim G_{t+1}(P) \end{cases} \tag{22}$$

If a bank posted a price P which is no longer in the equilibrium price support in period $t+1$, it chooses a new price P' from an equilibrium repricing distribution $G_{t+1}(P)$. The banks that posted prices in period t that are part of the new equilibrium price support in period $t+1$ have no incentive to reprice. These banks randomize and with probability $\rho > 0$ they keep their posted price and with probability $1-\rho$ they choose a new price from the equilibrium repricing distribution $G_{t+1}(P)$.

The changes in the marginal cost of funds are transmitted less than one for one to the minimal price (maximal yield) as can be seen from a first-order approximation of the effect of the marginal cost of funds on the minimum price (maximum yield) at $\sigma = 1$:

$$\frac{\partial P_{min}}{\partial \tilde{P}} \approx 1 - \frac{q_1}{\sum_{k=1}^{N} k q_k} < 1 \tag{23}$$

A higher fraction of the high information cost investors reduces the pass-through coefficient as a higher q_1 increases the banks' monopoly power and the size of the mark-up banks charge over marginal costs.

First, let us examine the effect of a monetary policy tightening. The marginal cost of funds is increased in a sequence of interest rate increases of size κ^+. Increases in the marginal cost of funds leads to a decreasing (increasing) sequence of minimum prices (maximum yields) over the period of the policy implementation $P_{min,t+T^+} < .. < P_{min,t+i} < .. < P_{min,t}$ for $i = 1, 2, .., T^+$. For the purpose of this exercise, I assume that the upper bound P_{max} remains unchanged. The supports of the new equilibrium price distributions contains the initial support. Given a parameter $\rho \in [0, 1]$ an admissible repricing strategy imposes restrictions on the repricing distribution. The law of motion of the sequence of equilibrium price distributions is described as:

$$F_{P,t+1}(P) = \begin{cases} (1-\rho)G^+_{t+1}(P) + \rho F_{P,t}(P) & \text{if } P \in (P_{min,t}, P_{max}] \\ (1-\rho)G^+_{t+1}(P) & \text{if } P \in [P_{min,t+1}, P_{min,t}] \end{cases} \tag{24}$$

A fraction $1-\rho$ of the prices within the initial equilibrium price support are generated from the new reprice distribution $G^+_{t+1}(P)$ and a fraction ρ of the non-adjusters are part of the previous period equilibrium distribution. All prices in the non-overlapping section of the new support $[P_{min,t+1}, P_{min,t}]$ are new prices drawn from the reprice distribution by the fraction of adjusters. To be admissible, the equilibrium repricing distribution must satisfy:

$$G^+_{t+1}(P) = \begin{cases} \frac{F_{P,t+1}(P) - \rho F_{P,t}(P)}{1-\rho} & \text{if } P \in (P_{min,t}, P_{max}] \\ \frac{F_{P,t+1}(P)}{1-\rho} & \text{if } P \in [P_{min,t+1}, P_{min,t}] \end{cases} \tag{25}$$

Starting from period t and tracking a price $P \in [P_{min,t}, P_{max}]$, after $1 < i \leq T^+$ periods the probability that the price changes in period $t+i$ and not earlier is $\rho^{i-1}(1-\rho)$. Since the initial price distribution support is always contained in the new price supports, all prices in the initial support have the same hazard rate of adjustment $1-\rho$. The average duration of prices in the initial price support during the policy implementation $[t, t+T^+]$ is:

$$D^+(\rho) = (1-\rho) \sum_{j=1}^{T^+} j \rho^{j-1} = \frac{1 - (T^+ + 1)\rho^{T^+} + T^+ \rho^{T^+ + 1}}{1-\rho} \tag{26}$$

During the regime of monetary policy tightening the banks are indifferent between repricing and not repricing as the equilibrium support is expanding and always contained in the previous period support. Each period a constant fraction of the banks decide to adjust their prices according to the repricing strategy (22).

$$\Phi^{+}(\rho) = 1 - \rho \tag{27}$$

The distribution of magnitude of price changes is derived as follows. During the period of monetary policy tightening a density of $(1-\rho)f_{t,P}(P)$ of the banks which posted a price P choose to adjust drawing a new price P' from $G^{+}_{t+1}(P')$. The fraction of banks that choose a new price that is at most δ percent higher is $G^{+}_{t+1}(P(1+\delta))$. The distribution of the magnitudes of price changes defined as $\Gamma^{+}_{t+1}(\delta,\rho) \equiv Pr(\frac{P'}{P} - 1 \leq \delta | \rho, T^{+})$ is

$$\Gamma^{+}_{t+1}(\delta,\rho) = \int_{P_{min,t}}^{P_{max}} G^{+}_{t+1}((1+\delta)P) f_{t,P}(P) dP \tag{28}$$

A policy of increasing interest rates under this repricing rule leads to the same duration and synchronization of price adjustments as would be the case if the policy was to keep interest rates constant. To see this, note that in both environments the initial equilibrium support remains a subset of the subsequent new equilibrium price supports. In the case of constant interest rate policy the equilibrium support does not change. This implies that the duration and synchronization of price adjustments is the same $D^{+} = D^{0}$ and $\Phi^{+} = \Phi^{0}$. The repricing distribution in the case of constant interest rate policy is $G^{0}_{t+1}(P) = F_{t,P}(P)$ which first-order stochastically dominates $G^{+}_{t+1}(P)$ as the support of the latter has a smaller lower bound. The distribution of the magnitudes of price changes is:

$$\Gamma^{0}_{t+1}(\delta,\rho) = \int_{P_{min,t}}^{P_{max}} F_{P,t}(P(1+\delta)) f_{t,P}(P) dP \tag{29}$$

Next, let us examine monetary policy which is expansionary and reduces the costs of funds of banks in a series of interest rates cuts of magnitude $\kappa^{-} > 0$ for T^{-} periods in a row. The overlapping set of consecutive price supports are shrinking over time $S_{t+i} \subset \mathcal{S}_{t+i-1} \subset .. \subset \mathcal{S}_{t}$ as $P_{min,t+i} > P_{min,t+i-1} > .. > P_{min,t}$ for $i = 1, 2, .., T^{-}$. Every period i during the policy regime a fraction $F_{P,t+i-1}(P_{min,t+i})$ of banks drops from the new price support and adjusts with probability one drawing a new price from the repricing distribution $G^{-}_{t+1}(P)$. The equilibrium price distribution evolves according to:

$$F_{P,t+1}(P) = F_{P,t}(P_{min,t+1})G^-_{t+1}(P) + (1 - F_{P,t}(P_{min,t+1}))(1-\rho)G^-_{t+1}(P) + \\ +(F_{P,t}(P) - F_{P,t}(P_{min,t+1}))\rho \tag{30}$$

The first term is the fraction of the banks that drop from the new equilibrium support and draw a new price from the repricing distribution $G^-_{t+1}(P)$. The second term constitutes the $1-\rho$ fraction of the banks which posted prices in period t which are still contained in the new repricing distribution $\mathcal{S}_{t+1}$ but which decide to reprice. Finally, the third term are the set of banks that do not reprice. The admissible repricing distribution is derived as:

$$G^-_{t+1}(P) = \frac{F_{P,t+1}(P) - (F_{P,t}(P) - F_{P,t}(P_{min,t+1}))\rho}{1 - \rho + \rho F_{P,t}(P_{min,t+1})} \tag{31}$$

To compute the average duration of prices in the original price support let us suppose that in period $t + T^-$ the price support shrinks but does not vanish $P_{min,t+T^-} < P_{max}$. Then for a price posted in time t in the interval $P \in [P_{min,t+i-1}, P_{min,t+i}]$ the probability of it being adjusted in period $j = 1, 2, .., i$ but not earlier is $(1-\rho)\rho^{j-1}$ and the expected duration is $\frac{1-(i+1)\rho^i + i\rho^{i+1}}{1-\rho}$. After period i this price adjusts with probability one as it falls out of the equilibrium price distribution support. There is an initial mass of $F_{P,t}(P_{min,t+i}) - F_{P,t}(P_{min,t+i-1})$ banks in this interval at time t. The expected duration of prices at time t for this policy regime is derived as the sum of the expected durations for these intervals weighted by the mass of banks in each interval.

$$D^-(\rho) = \sum_{i=1}^{T^- - 1} \Big(F_{P,t}(P_{min,t+i}) - F_{P,t}(P_{min,t+i-1})\Big)\frac{1-(i+1)\rho^i + i\rho^{i+1}}{1-\rho} + \\ +(1 - F_{P,t}(P_{min,t+T^-}))\frac{1-(T^-+1)\rho^{T^-} + T^-\rho^{T^-+1}}{1-\rho} \tag{32}$$

The fraction of adjusters in each period $t + i$ for $i = 1, 2, .., T_-$ is composed of the mass of banks that fall outside the new equilibrium support $F_{P,t+i-1}(P_{min,t+i})$ and the $1-\rho$ fraction of banks in the indifference region $\mathcal{Z}_{t+i}$ of mass $1 - F_{P,t+i-1}(P_{min,t+i})$

$$\Phi^-_{t+i}(\rho) = 1 - \rho + \rho F_{P,t+i-1}(P_{min,t+i}) \tag{33}$$

Finally, the distribution of the magnitude of price adjustments is computed as in the case of monetary policy tightening. Each period a fraction of $\Phi^-_{t+i}(\rho)$ banks adjust prices.

If a bank posted a price $P \in [P_{min,t}, P_{min,t+1}]$, it adjusts its price with probability one and the density of banks at this price is $f_{P,t}(P)$. The probability density of banks that adjust in the indifference region $\mathcal{Z}_{t+1} = [P_{min,t+1}, P_{max}]$ is $(1-\rho)f_{P,t}(P)$. The mass of banks that increase their price by at most δ percent is $G^{-}_{t+1}(P(1+\delta))$. Finally, combining the two regions and scaling by the fraction of adjusters the expression for the distribution of the magnitudes of price adjustments is

$$\Gamma^{-}_{t+1}(\delta, \rho) = \frac{1}{\Phi^{-}_{t+i}(\rho)} \int_{P_{min,t}}^{P_{max}} G^{-}_{t+1}((1+\delta)P)\Big(1 - \rho\mathcal{I}\{P \geq P_{min,t+1}\}\Big) f_{P,t}(P) dP \qquad (34)$$

The average duration of price adjustments in this policy regime is strictly lower than the previous two regimes $D^{-}(\rho) < D^{+}(\rho) = D^{0}(\rho)$ while the fraction of adjusters is strictly higher $\Phi^{-}_{t+i}(\rho) > \Phi^{+}_{t+i}(\rho) = \Phi^{0}_{t+i}(\rho)$. The magnitude of price adjustments are ordered as follows $\Gamma^{-}_{t+1}(\delta, \rho) < \Gamma^{0}_{t+1}(\delta, \rho) < \Gamma^{+}_{t+1}(\delta, \rho)$. In all regimes there is a positive mass of banks $0 < \Gamma^{\pm,0}_{t+1}(0, \rho) < 1$ that either reduce or increase their prices as well as a mass of banks that change their prices by small amounts around zero $\gamma^{\pm,0}_{t+1}(0, \rho) > 0$.

The results from this section emphasize that, at least qualitatively, within the framework of costly consumer search, it is possible to replicate both the observed price dispersion and the price rigidity observed in the pricing of insured time deposits. Moreover, the model is also able to fit the asymmetric response of price adjustment of deposit yields documented in Tables (2) and (3) in three distinct monetary policy regimes.

4 Model estimation

4.1 Maximum likelihood construction

I use the maximum likelihood method to estimate the parameters of the model relying on the likelihood function implied by the model. I follow the methodology of Hong and Shum [2006], Moraga-González and Wildenbeest [2008] and Moraga-González, Sándor, and Wildenbeest [2012] which allows to estimate the model parameters using information only on the observed price distribution without the need to have information on quantities as in Hortaçsu and Syverson [2004].

Proposition 4 *The model implied likelihood function is derived as:*

$$f_p(P|\Theta) = \begin{cases} \frac{\psi'(P)}{\psi(P)} \times \frac{\sum_{k=1}^{N} k q_k (1-F_P(P))^{k-1}}{\sum_{k=1}^{N} k(k-1) q_k (1-F_P(P))^{k-2}} & P \in \mathcal{S} \\ 0 & otherwise \end{cases} \qquad (35)$$

where $\psi(P) = (P - \tilde{P})(1 - h^d(P))$ *is the per investor profit function and the vector*

$\Big(F_P(P), P_{min}, P_{max}, \pi^{d*}, \{q_k\}_{k=1}^N, \dot{P}\Big)$ *is a market equilibrium (3.3) given the primitives of the model* $\Theta = \Big(F_\xi, \tilde{P}, E(P^r), \sigma_r^2, \sigma, \gamma\Big)$.

Proof See Appendix □.

Using the likelihood function defined in (35), I can obtain maximum likelihood estimates of the model where I can identify the shares $\{q_k\}_{k=1}^N$ but not the infinite dimensional object of the search cost distribution. In order to reduce the dimensionality of the parameter space, I approximate the unknown search cost distribution by a set of Hermite polynomials as in Gallant and Nychka [1987] and Fenton and Gallant [1996]. The approximating search cost distribution $f_\xi(\xi|\theta) \approx f_\xi(\xi)$ is parametrized by a low dimensional vector θ of size p. The parameter vector of the approximating model is $\Theta^p = \Big(\theta, \tilde{P}, E(P^r), \sigma_r^2, \sigma, \gamma\Big)$. Given a dataset of observed market prices $\{P_j\}_{j=1}^M$ of size M, the semi-nonparametric maximum likelihood problem is defined as:

$$max_{\Theta^p \in \Theta^p_{\mathcal{A}}} \Big\{ \frac{1}{M} \sum_{j=1}^{M} ln f_P(P_j|\Theta^p) \Big\} \quad (36)$$

subject to:

$(F_P(P), f_P(P),\ P_{min},\ \{q_k\}_{k=1}^N,\ h^d(P),\ P_{max})$is an equilibrium as defined in 3.3.

$\Theta^p_{\mathcal{A}}$ is the set of admissible parameter values.

The construction of the likelihood involves solving for the equilibrium as defined in section (3.3). [25]

4.2 Structural estimates

I estimate the search cost distribution for one representative market - Chicago-Naperville-Joliet [26] for the month of June of each year from 1997 - 2011.

The important features of this market for the relevant period market concentration has remained relatively constant. The number of banks and the HHI index remained relatively constant. [27] On the demand side, there was an increase in the nominal income per capita, deposits per capita as well as steady increase in the population of approximately 7 percent

[25] To maximize the likelihood function, I use the global optimization toolbox of Matlab (R) 2012a

[26] This was the market with the largest number of operating banks and the second largest in terms of population after New York-Northern New Jersey-Long Island.

[27] There has been an increase in the number of branches in the market which more than doubled over the 1997-2010 period but this trend is consistent with the rest of the economy.

Table 8: The summary statistics for Chicago-Naperville-Joliet, IL-IN-WI

	Pop.	Income	Number banks	Share 65+	HHI index	DISP 12-m
1997	8862719	30296	259	0.11	0.04	0.78
1998	8949190	32136	256	0.11	0.04	0.61
1999	9035654	33157	260	0.11	0.04	0.72
2000	9113234	35408	252	0.11	0.05	1.27
2001	9169580	35816	258	0.11	0.05	0.92
2002	9206032	36367	253	0.11	0.05	0.97
2003	9233303	37021	293	0.11	0.08	0.79
2004	9260676	38723	292	0.11	0.06	0.95
2005	9276302	40481	266	0.11	0.07	1.52
2006	9297749	43294	263	0.11	0.07	2.02
2007	9337140	45466	264	0.11	0.06	1.78
2008	9384555	46769	262	0.11	0.06	1.29
2009	9429498	45090	259	0.11	0.06	1.04
2010	9474363	45957	241	0.11	0.06	0.70

NOTE: The column "Income" measures income per capita. Share 65+ is the share of the population of age 65 or above. The HHI index takes values from 0 (least concentrated) to 1 (the most concentrated) and is constructed based on the deposit amounts reported in the Summary of Deposits (SOD) dataset. DISP 12-m is the average for the corresponding year of the DISP(P(.90) - P(.10)) measure of yield dispersion.

over this period which were consistent with trends in the rest of the economy. The share of the most active segment of investors in the CD market - the population age 65 and above, however, remained constant at 11 %. The relatively constant market concentration and share of the most active investors in CDs gives us a stable environment to identify the search cost distribution.

I present estimates of the model using data on the 12-month CD contract [28]. The two sample Kolmogorov-Smirnov (KS) test presented in Table (9). The model is successful at generating a price distribution which is close to the empirically observed in 2005, 2006, 2007 and 2011 for which the KS-test fails to reject the null hypothesis at 5 percent significance level. The goodness of fit of the model seems to improve from 2003 onwards. To further examine the ability of the model to match the distribution of yield offers, I plot the empirically observed price distribution for selected years in Figure (5) along with the model generated. What is immediately obvious from the plots is that the model is successful at fitting the low (high) percentiles of the price (yield) distribution. However, the

[28] I estimate the model with all maturities but choose to present the results for the 12-month contract. The results are qualitatively similar across maturities.

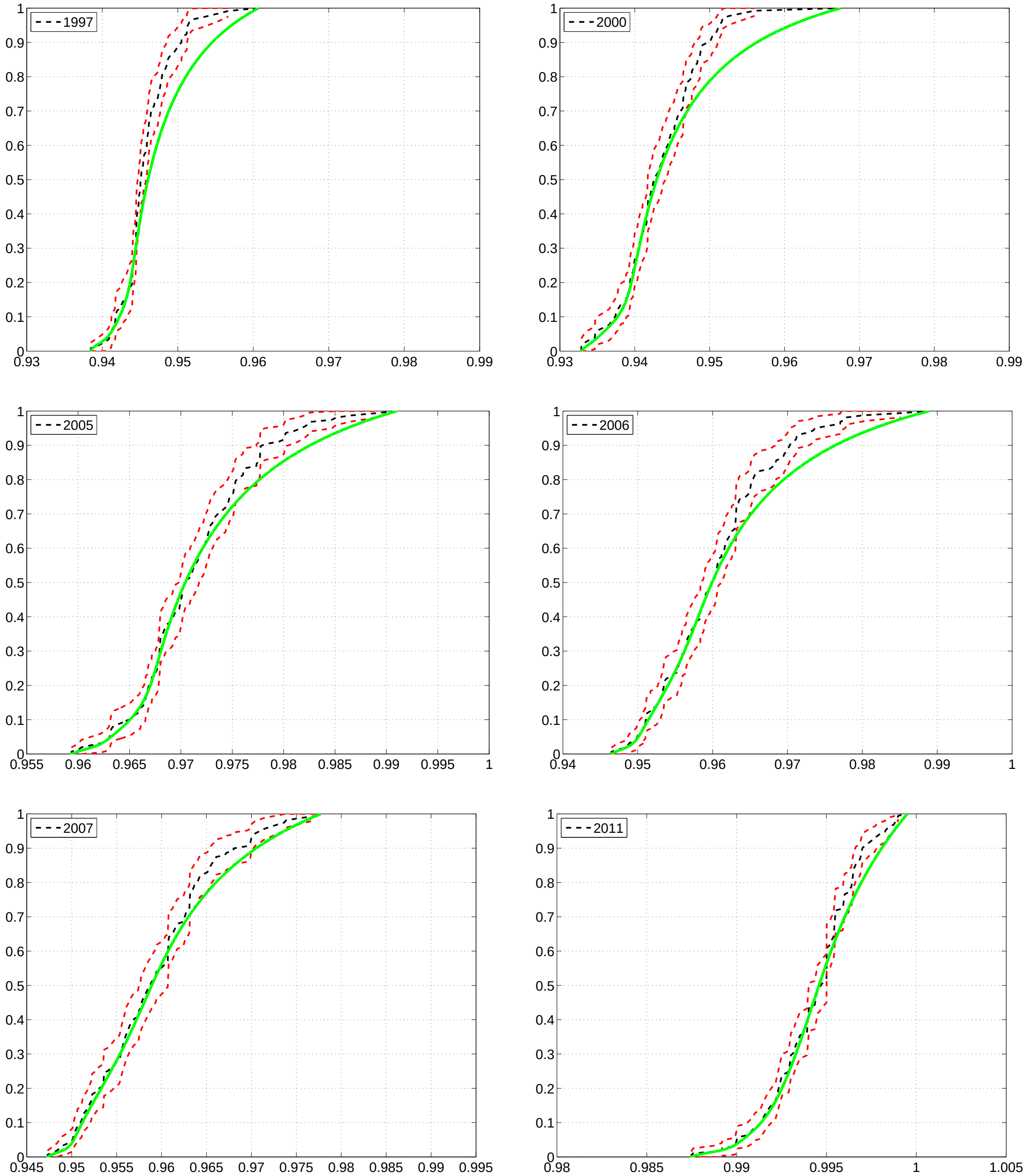
Table 9: The Kolmogorov-Smirnov test for equality between the empirical price CDF and the model generated

	KS stat	**KS p-value**
1997	0.17	0.00
1998	0.21	0.00
1999	0.33	0.00
2000	0.14	0.01
2001	0.21	0.00
2002	0.15	0.00
2003	0.19	0.00
2004	0.13	0.02
2005	0.09	0.12
2006	0.10	0.08
2007	0.07	0.35
2008	0.13	0.01
2009	0.12	0.01
2010	0.13	0.01
2011	0.09	0.06

NOTE: The two-sample Kolmogorov-Smirnov test is defined as the test statistic $\sqrt(N)D_N \rightarrow sup_t|B(F_P(t))|$ where $D_N = sup_x|F_P^N(x) - F_P(x)|$ and $B(\cdot)$ is Brownian bridge. The model generated CDF distribution $F_P(x)$ is compared to the empirical distribution $F_P^N(x)$ where N indexes the sample size. The table presents the values of the test statistic and the p-values for the 12-month CD contract. The null hypothesis is that the two distributions are the same.

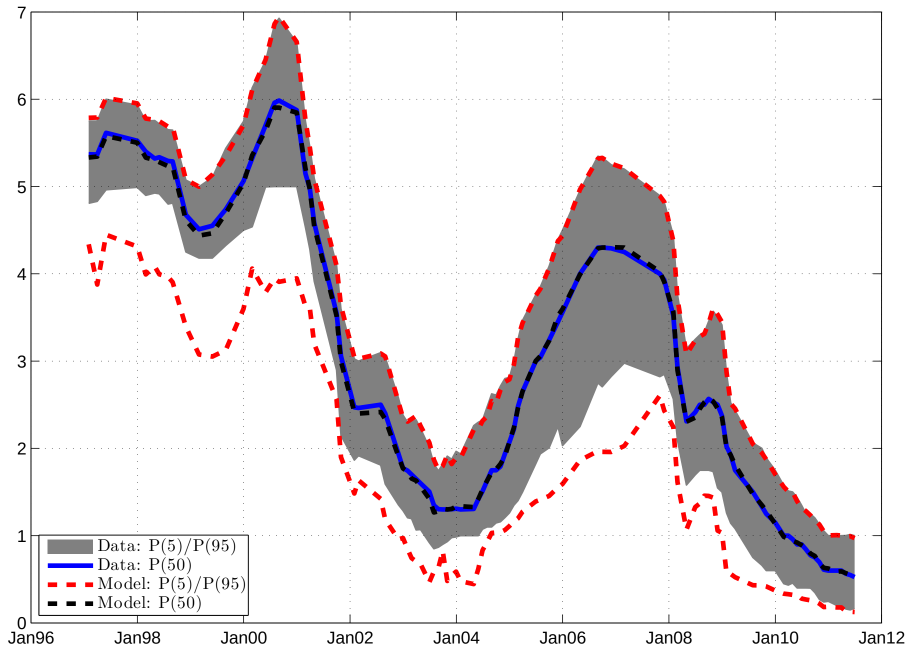
model generates more mass in the high (low) price (yields) percentiles. This is a consistent pattern for all the periods of estimation. The upper panel of Figure (6) plots the time series variation of the percentiles $P(.05)$ and $P(.95)$ of the model generated price distributions and the ones observed in the data. The model fits precisely the $P(0.95)$ and the median $P(0.5)$ but generates a significantly lower $P(0.05)$ as suggested by Figure (5). The model generates a higher price dispersion than the one observed in the data by fitting an implied yield distribution which is skewed to the left relative to the data. A larger mass of banks was able to post lower yields that what we observe in the data. Hence, the model over predicts the extent of monopoly power enjoyed by the banks for the earlier periods in the sample.

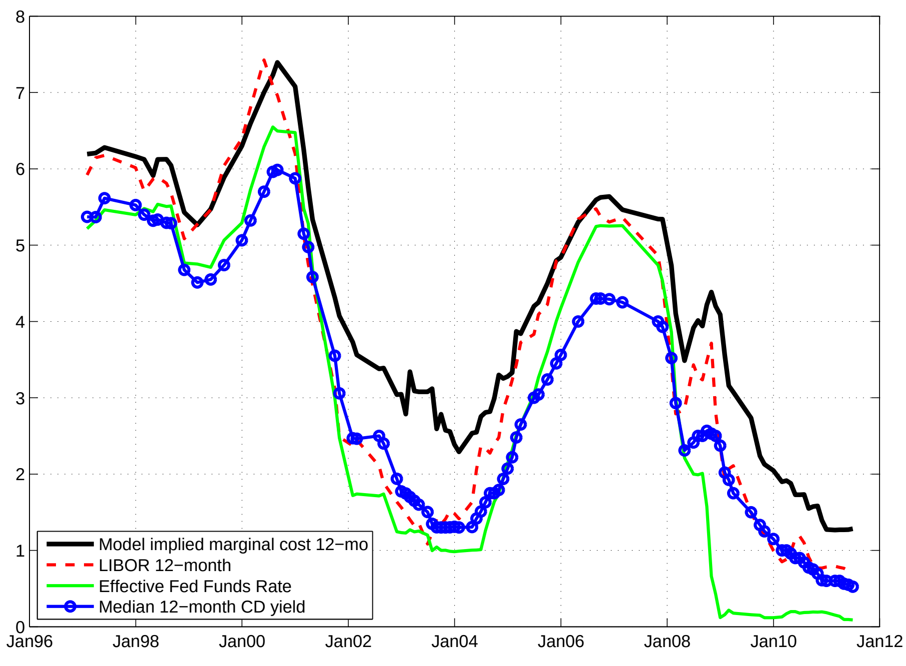
Figure 5: The empirical price distribution and the model generated



NOTE: The dashed black line is the observed empirical CDF of the prices for the 12-month contract for the month of June of the selected years. The two dashed red lines define the 90 percent confidence interval for the empirical CDF using Kaplan-Meier estimator. The thick green line is the model generated equilibrium distribution based on the estimates of the structural parameters.

Figure 6: The model implied distribution of yields and marginal cost of funds





NOTE: The upper panel of the figure plots the model implied percentiles P(.05)/P(.95) (dashed red lines) against the realized distribution P(5)/P(95) (shaded area) along with the model implied median P(0.5) (black dashed line) and the median in the data (blue line). The lower panel of the figure plots the model implied marginal cost of funds and a set of empirical proxies. The data and calculations are based on Chicago-Naperville-Joliet MSA area monthly observations 1997 - 2011 for the 12-month CD contract.

One plausible explanation for the inability of the model to fit the empirical price distributions for a number of years in the sample in this particular way could be the strong assumption that the banks faced a common marginal cost in supplying deposits. Therefore, a somewhat indirect test for the goodness of fit of the model is presented in the lower panel of Figure(6) which plots the model implied marginal cost of funds. It also plots the matched maturity 12-month LIBOR which is a common benchmark rate for the marginal cost of funds along with the effective fed funds rate. Remarkably, the model implied marginal cost of funds closely tracks the LIBOR for a number of years. On average, however, the model implies a much higher marginal cost as compared to these empirical proxies. The banks that had access and borrowed from the LIBOR and the fed funds markets were mainly much larger and geographically diversified banks than the median bank in the sample. The median bank in the sample was much smaller and its operations were usually restricted to a given state or even metropolitan area. To the extent that smaller banks faced higher costs of accessing external finance in the wholesale funding markets, the model correctly picks a higher on average marginal costs.

A further plausible explanation for why the model is not be able to fit the lower percentiles of the yield distribution could come from the demand side. I have used a set of strong assumptions on the linearity of the search cost technology with respect to wealth and I have also not explicitly modeled switching costs. Higher wealth could have a non-linear effect on the intensity of search and hence on the ability of banks to post lower yields which is certainly true for investors with deposits exceeding the insurance limit. Similarly, switching costs could vary due to the presence of long-term relationships with a bank and bundling of other services such as checking accounts, credit cards and consumer loans.[29]

The next set of figures examines the estimated distribution of search cost types and the intensity of search implied by the model. The estimates of the search cost distribution are displayed in Figure (7) which plots the estimated cumulative density function of the search cost distributions implied by the model for two sub-samples 1997-2001 and 2002-2007. The first sub-sample 1997-2001 could be roughly labeled the "pre-Internet banking period" during which banks started adopting the newly developed Internet technologies.[30] I label the second period 2002-2007 is the "Internet banking period" during which Internet banking was extensively introduced and adopted. The figure also plots the 5th and 95th percentiles of the estimated search cost distributions for the two sub-samples computed. The estimation results show that the population of investors can be roughly split into two

[29]The model cannot distinguish between switching costs and search costs for the set of investors that optimally decide to sample only once as the first sample offer is assumed to be costless.

[30]According to a study of the Office of the Comptroller of the Currency by year-end the end of 2001, 50 percent of commercial banks offered internet banking services. I use this landmark value as a dividing line between the pre-Internet banking and the Internet banking period.

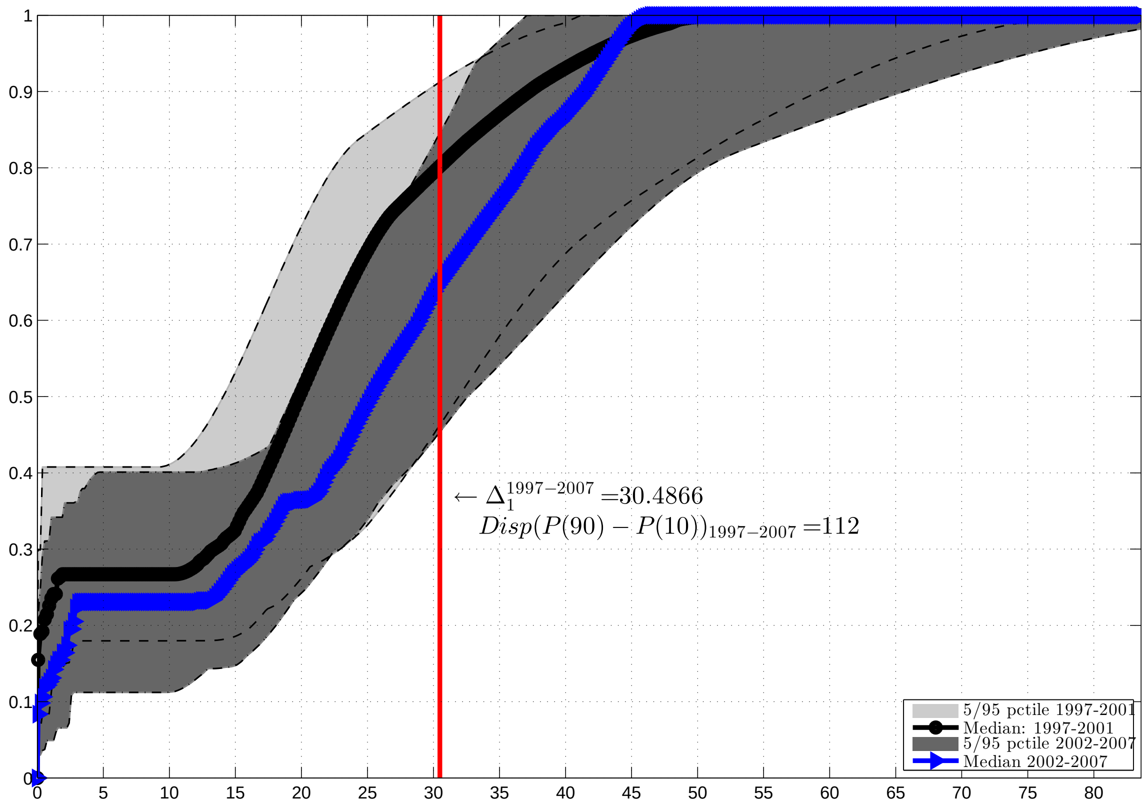
distinct groups which were present in both sub-samples. The first group is the group of low information cost investors whose search costs do not exceed 5 basis points. This segment of low information cost investors was 28 percent of the population in the earlier sample and measured at 24 percent in the later sample. A fraction of investors had search costs very close to zero and this segment has decreased from 16 percent of the population during the period of 1997-2001 to 8 percent during the later sample. The second group of investors were the high information cost investors whose search costs ranged exceeded 10 basis points to more than 50 basis points. A second fact that comes from this figure is that the entire search cost distribution has shifted to the right with the median search cost increasing from 20 basis points in the first sub-sample to 25 basis points in the second.

The marginal benefit from sampling a second bank offer is presented as a vertical red line on the graph and measures at 30.48 basis points for the 1997-2007 period. The measure of dispersion $DISP(P(90) - P(10))$ for this period is 112 basis points. From the discussion on the model, the cut-off value Δ_1 determines the fraction of the uninformed investors $q_1 = 1 - F_\xi(\Delta_1)$ who sample only once from the distribution of offers as their search costs must exceed Δ_1. This estimate, however, is an approximation as the incentives to search are determined endogenously by the equilibrium yield dispersion. It changes from one period to the next as the marginal cost of funds change. The estimation proceeds by estimating the model for each month and then averaging the results for each year. The next set of plots examine in detail the time series variation of the estimated share of uninformed and informed investors as well as the incentives to search as measured by the estimate of Δ_1.

Figure (8) plots the estimates of the share of uninformed investors $q_{1,t}$ who sample only one offer and the share of informed investors $q_{N_t,t}$ who sample all the banks' offers. The fraction of uniformed investors is high, averaging 32 percent of all investors over the sample period. The share of this group of investors is decreasing with the level of the yield dispersion as the incentives to search are higher during periods of high yield dispersion. On the other extreme, the fraction of informed investors has steadily decreased over the sample period from 20 percent in 1997 to close to 7 percent in 2007. [31]

[31] I estimate the whole sample period of available data including the crisis period post 2008. It could be well argued that the model does not fully capture the dynamics of the marginal cost of funds and the degree of changes in risk-aversion during the financial crisis period. However, it is interesting to note, that the model captures well the dynamics of the average marginal cost of funds as seen in Figure (6) and discussed in the text. The share of informed investors increases to 20 percent in 2010.

Figure 7: The estimated search cost distribution

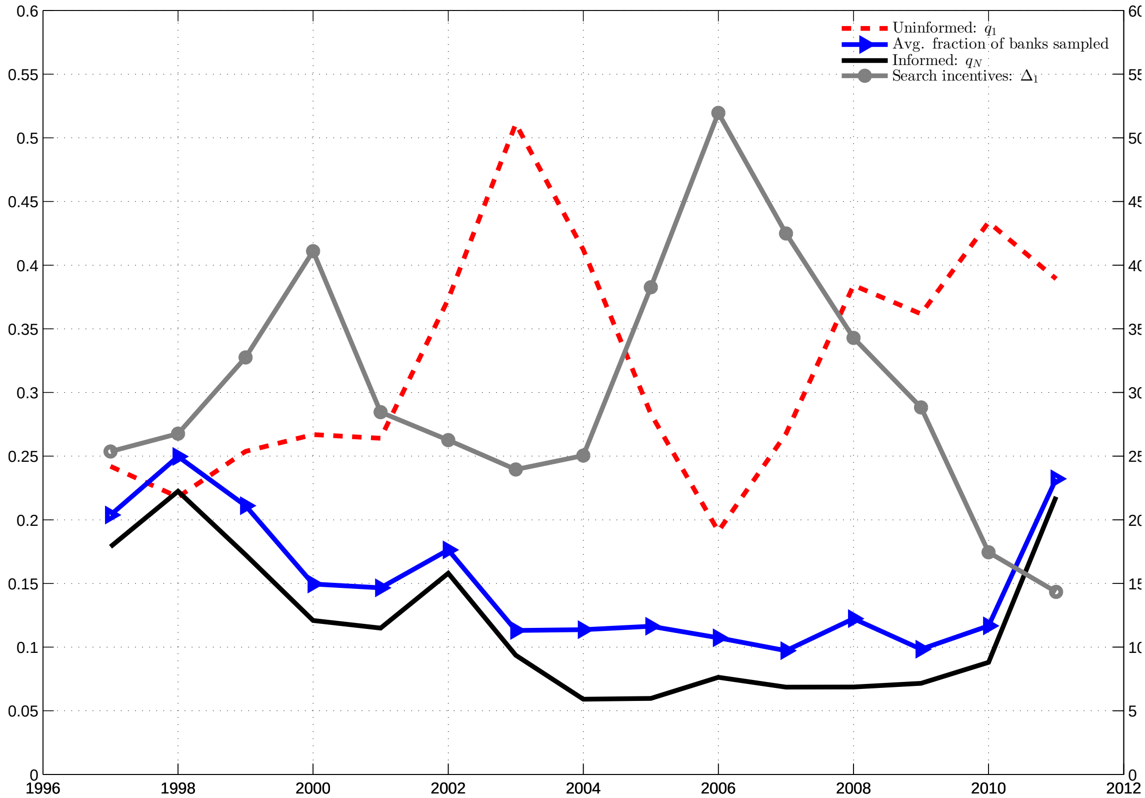


NOTE: The figure plots the estimated median CDF of the search cost distribution for two sub-periods 1997-2001 and 2002-2007. The shaded areas are the 5/95th percentiles of the search cost CDF $\hat{F}_{\xi}(\cdot)$ estimates for the two sub-periods. The search costs are expressed in basis points on the x-axis. The black (-o) line is the median CDF of the search cost distribution for 1997-2001 period and the blue $(->)$ line is the CDF for the 2002-2007 period. The vertical red line gives the average value of Δ_1 for the period 1997-2007.

The segment of uninformed investors is the main driver of the monopoly power for the banks in the model as well as the magnitude of the yield dispersion as shown in equation (21). The sample period 1997-2011 covers a period over which internet use and internet banking technologies were rapidly introduced and adopted. These technologies should have reduced both the cost of acquiring information about the deposit offers but also the switching costs of opening a new account with an institution different from the main bank.[32]

[32]Websites such as BankRate.com and Google-Finance allow one to compare rates across banks and markets on a centralized internet platform where banks can post rates. In fact RateWatch data provider is also organized in a similar way where banks voluntary provide the rates they offer on CDs.

Figure 8: The intensity of search



NOTE: The figure plots the time series variation of the model implied share of the uninformed (q_1) and the informed (q_N) investor segments. It also plots the average fraction of banks sampled computed as $\sum_{k=1}^{N} \frac{k}{N} q_k$. The gray (-o) line plots the measure of the incentives to search Δ_1 on the right y-axis expressed in basis points.

Regardless of this innovation in information technology, neither the observed price dispersion, nor the estimated fraction of uninformed investors experienced any significant decline. On the contrary the observed price dispersion documented in Figure (2) more than doubled over this period. The ability of the banking system to sustain large price dispersion despite the increased information technology use is a puzzle. The model captures this trend in the price dispersion as an increase in the median search cost and the upper percentiles of the search cost distribution as well as the steady decline in the share of the informed investors discussed above. It seems that the investors in the certificate of deposit market have not taken full advantage of the information technologies. This is consistent with a survey conducted by the Census which reports that 41.8 percent of U.S. households with heads of age above 55 have no internet connection in 2009 [33]. As regards to making financial decisions less than 20 percent of U.S. households relied on information available on the Internet to make investment and savings choices. [34].

The findings in this paper mirror results in Hortaçsu and Syverson [2004] who document an increase in the price dispersion and proliferation of S&P 500 index funds over the same period. They attribute these trends to entry of novice investors with high search costs. They also document a similar patterns for the retail money market mutual funds that give access to small investors to the treasury market and compete with banks in providing access to a safe interest paying alternative to bank deposits. In fact, the money market mutual funds industry developed as a response to Regulation Q during the high-inflation period of the late 1970s when the ceiling on the interest rates banks could pay on their deposits started to bind and investors were looking for alternatives. Since the 1970s banks have started to lose their deposit customers to money market mutual funds and the share of insured deposits has steadily declined. This process continued in the post-Regulation Q era. The exit of more sophisticated investors from the market for CDs into the money market mutual funds could explain why advances in information technology surprisingly left this market intact. It could also explain the pricing patterns in the mutual fund industry if the low information cost investors who exited the traditional deposit market turned to be the high information cost investors in the relatively new and more sophisticated mutual fund markets.

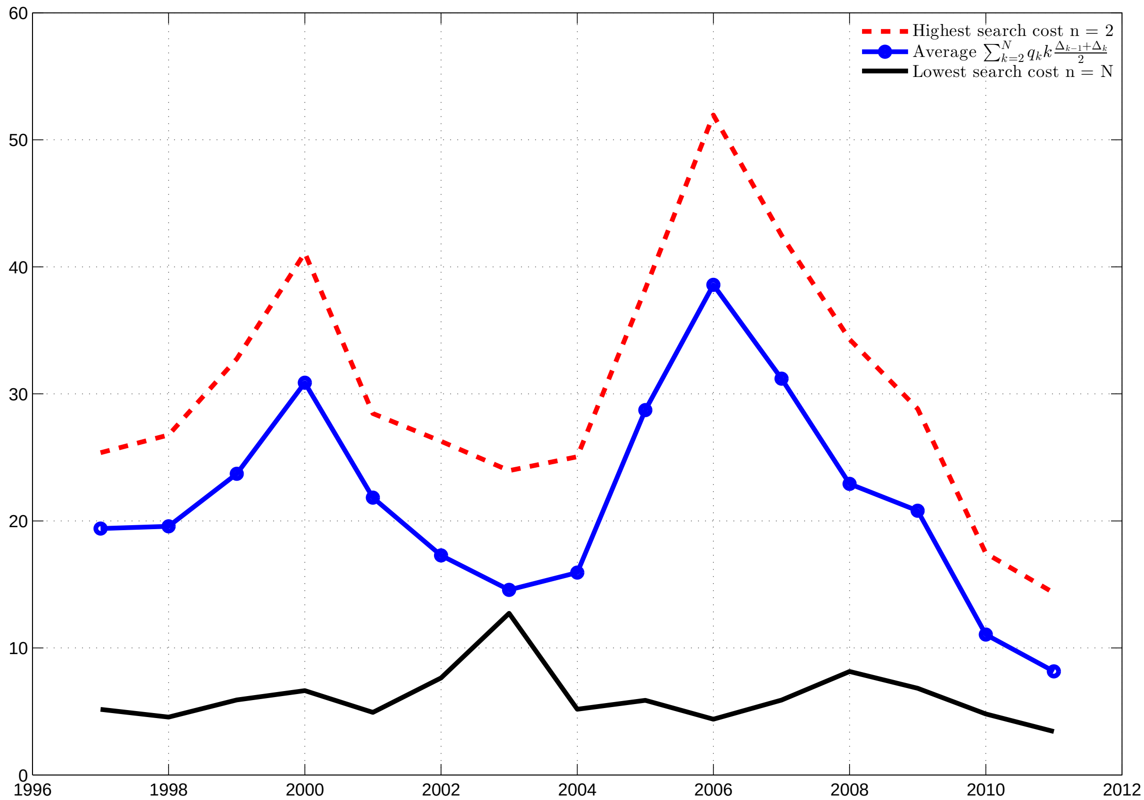
5 Welfare analysis

Search is socially wasteful. In the case of unitary intertemporal elasticity of substitution set, social optimum could be achieved if all banks charged the monopoly price and the investors invested in their first deposit offer avoiding costly search altogether. Institutionally, this could be achieved by a single mutual fund. No deadweight loss is generated as the demand for savings is price-inelastic and the investors' surplus is transferred as profits to this mutual fund. Instead, sizable resources are spent in search for the best return on a virtually homogeneous financial product.

[33] Source: U.S. Census Bureau, Current Population Survey, October 2009.

[34] Source: Survey of Consumer Finances, 2007

Figure 9: The magnitude of total search costs



NOTE: The figure plots the time series variation of the total search cost for the uninformed (q_1), the informed (q_1) and the average investor search cost computed as $\sum_{k=2}^{N} q_k k \frac{\Delta_{k-1}+\Delta_k}{2}$

The estimates of these costs are plotted in the lower panel of Figure (9). The average investor in this market spent between 10 to 40 basis points in total search costs over the sample period in search for a better yield on her savings. The incentives to search were higher during periods of higher yield dispersion. The implied search costs for the uniformed investors varied between 15 to 50 basis points. The segment of informed low search cost investors who observed the best yield offered spent on average 6 bps in total search costs.

These estimates provide a lower bound on the magnitude of the welfare losses in this market. The distortions in the market would be even higher if one allowed for the intertemporal elasticity of substitution to be different from one. In this case, the lower return on savings relative to the much higher marginal cost of supplying deposits distorts the degree of desired consumption-smoothing from what would be achieved in a perfectly competitive market where investors earned the higher competitive rate of return.

The standard monopoly deadweight losses apply to this market. Moreover, in the case of elastic intensive demand for deposits, the riskiness of the deposit offer distribution reduces further the welfare in the market as investors are risk-averse, they would exert more search effort than the case where their intensive demand for deposits is price inelastic.

6 Conclusion

Using a novel proprietary dataset, I have examined the unique characteristics of the pricing behavior of the U.S. commercial banks in the market for FDIC insured certificates of deposit. This pricing behavior is inconsistent with the law of one price and no arbitrage for this highly homogeneous financial product. I have rationalized the pricing behavior of the banks by the presence of heterogeneous search cost investors. To characterize the implied distribution of these search costs, I have constructed and estimated an asset pricing model with heterogeneous search cost investors in which banks compete as in Burdett and Judd [1983] facing a common marginal cost of funds determined by the monetary authority. I have uncovered that a large fraction of high information cost investors bestowed the monopoly power to the banks in this market. Information costs in the magnitude of 10-50 basis points of this high information cost segment of the market led to the sizable price dispersion.

The unique feature of the market for time deposits that sets it apart from other markets which are characterized by price dispersion, is that all the banks were subject to the same common variation in their marginal cost of funds determined by the actions of the Federal Reserve. However, the banks adjusted the rates on their time deposits rigidly and asymmetrically. The costly information acquisition hypothesis is consistent with such behavior. In the model, given that the pricing strategies played by banks generate an equilibrium price distribution over which banks earn the same profits, some fraction of the banks have no incentive to adjust the yields and do not reprice after a change in the fed funds rate. Changes in the fed funds rate are, thus, not fully transmitted into the deposit rates. To the extent that the reservation yield does not vary as much as the marginal cost of funds of banks, increases in the fed funds rate are transmitted into the time deposit yields much slower and with much longer price adjustment spells as compared to regimes during which the fed funds target rate is decreased. This generates the pro-cyclical yield dispersion and the asymmetric price adjustment patterns without the need to impose restrictions on the repricing behavior of the banks by imposing menu costs, for example.

In the standard models of price rigidity, such as the Calvo-price setting or the menu cost models, the generated price dispersion is the result of the inability of producers to adjust prices in the face of changing aggregate conditions. Absent shocks, however, the price distribution is degenerate at the monopolistically competitive price. In the model of costly consumer search of this paper, the price dispersion and the price rigidity are derived from micro-foundations and are the two sides of the same coin. While previous research on price rigidity usually ignores the resulting price dispersion[35] and examines the distribution of price changes, what I claim in this paper is that there is useful information in the time variation of the resulting price dispersion for distinguishing between competing theories of price setting behavior in retail markets.

Finally, viewed from the perspective of the sizable estimated search costs and the importance of the deposit market for determining the aggregate saving behavior of households, the increase in the dispersion of the yield offers on time deposits over the sample period reveals sizable welfare losses and potential distortion in the saving behavior of the U.S. households. These welfare losses should be a subject to policy debate from improving financial literacy to designing private social security systems. In a series of papers Mitchell, Lusardi, and Curto [2009] and Lusardi, Mitchell, and Curto [2010] document that both young and elderly households in the U.S. showed little financial literacy for making informed financial decisions. The estimated large and increasing information costs for obtaining the best rate of return for such a traditional savings vehicle, and despite advances in information technology over the period, is just a manifestation of the problems associated with inadequate financial literacy. Given that households are now required to make informed decisions on their social security and retirement investments, the findings in this paper are of importance for guiding policy design.[36]

[35] An notable exception is Lach [2002] who tests the costly information acquisition hypothesis with data from Israel on a set of homogeneous non-financial products. However, he does not relate the price dispersion with the underlying price rigidity.

[36] See an important study McKay [2011] which finds that privatization of social security can lead to sizable welfare losses in a market where households face information costs.

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