The Cost of Financial Frictions for Life Insurers*

Ralph S.J. Koijen† Motohiro Yogo‡

April 8, 2013

Abstract

During the financial crisis, life insurers sold long-term policies at deep discounts relative to actuarial value. In December 2008, the average markup was −19 percent for life annuities and −57 percent for universal life insurance. This extraordinary pricing behavior was a consequence of financial frictions and statutory reserve regulation that allowed life insurers to record far less than a dollar of reserve per dollar of future insurance liability. We identify the shadow cost of financial frictions through exogenous variation in required reserves across different types of policies. The shadow cost was \$2.32 per dollar of statutory capital for the average insurance company from November 2008 to February 2009. (*JEL* G01, G22, G28)

---

*A.M. Best Company, WebAnnuities Insurance Agency, and Compulife Software own the copyright to their respective data, which we use with permission. We thank Mary Anomalay, Jahiz Barlas, Minsoo Kim, Peter Nebres, and Julia Pei for assistance in putting together the data on annuity and life insurance prices. For comments and discussions, we thank Jennie Bai, Jeffrey Brown, Itamar Drechsler, Kenneth Froot, Stefano Giglio, Zain Mohey-Deen, Ľuboš Pástor, Anna Paulson, Michael Roberts, David Scharfstein, Amir Sufi, Annette Vissing-Jørgensen, and seminar participants at Aalto University, Copenhagen Business School, Emory University, Federal Reserve Bank (Atlanta, Boston, Chicago, Minneapolis, and San Francisco), London Business School, MIT, Norwegian Business School, Oxford University, Princeton University, Stanford University, University of British Columbia, UCLA, University of Chicago, University of Houston, University of Minnesota, University of Tokyo, University of Washington, University of Wisconsin, the 2012 SED Annual Meeting, the 2012 NBER Summer Institute Capital Markets and the Economy Workshop, the 2012 System Committee Meeting on Financial Structure and Regulation, the 2012 Wharton Conference on Liquidity and Financial Crises, the 2012 NBER Public Economics Program Meeting, the 2012 Boston University/Boston Fed Conference on Macro-Finance Linkages, the 2013 Utah Winter Finance Conference, and the 2013 NBER Insurance Working Group Meeting. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis, the Federal Reserve System, or the National Bureau of Economic Research.

†University of Chicago, Booth School of Business, 5807 South Woodlawn Avenue, Chicago IL 60637, NBER, and Netspar-Tilburg University (e-mail: ralph.koijen@chicagobooth.edu)

‡Federal Reserve Bank of Minneapolis, Research Department, 90 Hennepin Avenue, Minneapolis, MN 55401 (e-mail: yogo@minneapolisfed.org)

Traditional theories of insurance markets assume that insurance companies operate in an efficient capital market that allows them to supply policies at actuarially fair prices. Consequently, the market equilibrium is primarily determined by the demand side, either by life-cycle demand (Yaari 1965) or by informational frictions (Rothschild and Stiglitz 1976). In contrast to these traditional theories, this paper shows that insurance companies are financial institutions whose pricing behavior can be profoundly affected by financial and regulatory frictions.

Our key finding is that life insurers reduced the price of long-term policies from November 2008 to February 2009, when historically low interest rates implied that they should have instead raised prices. The average markup, relative to actuarial value (i.e., the present value of future policy claims), was −16 percent for 30-year term annuities and −19 percent for life annuities at age 60. Similarly, the average markup was −57 percent for universal life insurance at age 30. These deep discounts are in sharp contrast to the 6 to 10 percent markup that life insurers earn in ordinary times (Mitchell, Poterba, Warshawsky and Brown 1999). In the cross section of policies, the price reductions were larger for those policies with looser statutory reserve requirements. In the cross section of insurance companies, the price reductions were larger for those companies that suffered larger balance sheet shocks (i.e., lower asset growth, higher leverage, and larger deficit in risk-based capital).

This extraordinary pricing behavior precipitated from a remarkable coincidence of two circumstances. First, the financial crisis had an adverse impact on insurance companies' balance sheets, especially those companies with large deferred (fixed and variable) annuity liabilities whose guarantees (i.e., embedded put options) turned out to be unprofitable. Second, statutory reserve regulation in the United States allowed life insurers to record far less than a dollar of reserve per dollar of future insurance liability around December 2008. Since rating agencies and state regulators assess insurance companies based on an accounting measure of liabilities, these companies ultimately care about accounting (rather than market) leverage. Insurance companies were able to generate accounting profits by selling policies at a price far below actuarial value, as long as that price was above the reserve value.

We formalize our hypothesis in a dynamic model of insurance pricing that is otherwise standard, except for a leverage constraint that is familiar from macroeconomics and finance (e.g., Kiyotaki and Moore 1997, Brunnermeier and Pedersen 2009). The leverage constraint captures the fact that insurance companies are rated and regulated because of the potential for excessive risk taking that may arise for various reasons (e.g., presence of state guaranty funds or principal-agent problems). The insurance company sets prices for various types of policies to maximize the present value of profits, subject to a leverage constraint on the value of its assets relative to statutory reserves. When the leverage constraint binds, the insurance company optimally prices a policy below its actuarial value if its sale has a negative marginal impact on leverage. The Lagrange multiplier on the leverage constraint has a structural interpretation as the shadow cost of raising a dollar of statutory capital.

We test our hypothesis on panel data of over 50,000 observations on insurance prices from January 1989 to July 2011. Our data cover term annuities, life annuities, and universal life insurance for both males and females as well as various age groups. Relative to other industries, life insurance presents a unique opportunity to identify the shadow cost of financial frictions for two reasons. First, life insurers sell relatively simple products whose marginal cost can be accurately measured. Second, statutory reserve regulation specifies a constant discount rate for reserve valuation, regardless of the maturity of the policy. This mechanical rule generates exogenous variation in required reserves across policies of different maturities, which acts as relative shifts in the supply curve that are plausibly exogenous.

We find that the shadow cost of financial frictions was \$2.32 per dollar of statutory capital for the average insurance company from November 2008 to February 2009. This cost varies from \$0.76 to \$17.83 per dollar of statutory capital for the cross section of insurance companies in our sample. Those companies with the highest shadow costs substantially increased the quantity of policies issued while reducing prices, consistent with a downward shift in the supply curve. In addition, those companies with the highest shadow costs were actively recapitalizing through two conventional channels. First, more constrained companies reduced their required risk-based capital by shifting to safer assets with lower risk charges, such as cash and short-term investments. Second, more constrained companies received larger capital injections from their holding company and reduced stockholder dividends. We find evidence that these capital injections may have been limited by frictions in internal capital markets that arise from incentives created by regulatory restrictions on capital flows.

We rule out the theory of price wars as an alternative hypothesis. A version of the theory based on persistence in market shares (Chevalier and Scharfstein 1996) comes closest to explaining the evidence, by predicting pricing below marginal cost when aggregate demand is weak. However, this theory has a counterfactual prediction that the market share decreases for those companies that reduce prices more. Moreover, this theory does not explain other important facts such as the cross-sectional relation between price reductions and leverage, the absence of discounts in other periods of weak demand, and the variation in discounts across policies of different maturities.

We also rule out default risk as an alternative hypothesis. We find that the markups on term annuities are too low to be justified by default risk, given reasonable assumptions about the recovery rate. Moreover, the term structure of risk-neutral default probabilities implied by term annuities does not match that implied by credit default swaps in magnitude, slope across maturity, or variation across insurance companies. We also find out-of-sample evidence against default risk based on the absence of discounts on life annuities during the Great Depression.

Our finding of fire sales on the liability side of the balance sheet complements related evidence on the asset side during the financial crisis. Financially constrained life insurers sold downgraded bonds at fire-sale prices in order to reduce their required risk-based capital (Merrill, Nadauld, Stulz and Sherlund 2012). They also sold corporate bonds with the highest unrealized capital gains, carried at historical cost according to the accounting rules, in order to improve their capital positions (Ellul, Jotikasthira, Lundblad and Wang 2012).

Relative to the asset side, an advantage of the liability side is that the counterfactual (i.e., pricing in the absence of financial frictions) can be more accurately measured, so that we can quantify the cost of financial frictions.

Our finding that the supply curve for life insurers shifts down in response to a balance sheet shock, causing insurance prices to fall, contrasts with the evidence that the supply curve for property and casualty insurers shifts up, causing insurance prices to rise (Froot and O'Connell 1999). Although these findings may seem contradictory at first, they are both consistent with our supply-driven theory of insurance pricing. The key difference between life insurers and property and casualty insurers is statutory reserve regulation. Life insurers were able to relax their leverage constraint by selling new policies because their statutory reserve regulation allowed less than full reserve during the financial crisis. In contrast, property and casualty insurers must tighten their leverage constraint when selling new policies because their statutory reserve regulation always requires more than full reserve.

The remainder of the paper is organized as follows. Section 1 describes our data and documents key facts that motivate our study of insurance prices. Section 2 reviews key features of statutory reserve regulation that are relevant for our analysis. In Section 3, we develop a structural model of insurance pricing, which shows how financial frictions and statutory reserve regulation affect insurance prices. In Section 4, we estimate the shadow cost of financial frictions through the structural model. In Section 5, we rule out the theory of price wars and default risk as alternative hypotheses. Section 6 concludes with broader implications of our study for household finance and macroeconomics.

1. Annuity and Life Insurance Prices

1.1. *Data Construction*

1.1.1. Annuity Prices

Our sample of annuity prices is from the WebAnnuities Insurance Agency, which has published quotes from the leading life insurers at a semiannual frequency from January 1989 to July 2011 (Stern 1989–2011) and at a monthly frequency from January 2007 to August 2009 (Stern 2007–2009). Following Mitchell et al. (1999), we focus on single premium immediate annuities in nonqualified accounts (i.e., only the interest is taxable). Since the premium is paid up front as a single lump sum, these policies cannot be lapsed. Our data consist of two types of policies: term and life annuities. For term annuities, we have quotes for 5- to 30-year maturities (every 5 years in between). For life annuities, we have quotes for "life only" policies without guarantees as well as those with 10- or 20-year guarantees. These quotes are available for both males and females aged 50 to 85 (every 5 years in between).

A term annuity pays annual income for a fixed maturity of M years. Since term annuities have a fixed income stream that is independent of survival, they are straight bonds rather than longevity insurance. An insurance company that issues a term annuity must buy a portfolio of Treasury bonds to replicate its future cash flows. A portfolio of corporate bonds, for example, does not perfectly replicate the cash flows because of default risk. Therefore, the law of one price implies that the Treasury yield curve is the appropriate cost of capital for the valuation of term annuities. Let $R_t(m)$ be the zero-coupon Treasury yield at maturity m and time t. We define the actuarial value of an M-year term annuity per dollar of income as

$$V_t(M) = \sum_{m=1}^{M} \frac{1}{R_t(m)^m}. \tag{1}$$

We calculate the actuarial value for term annuities based on the zero-coupon yield curve for off-the-run Treasury bonds (Gürkaynak, Sack and Wright 2007).

A life annuity with an M-year guarantee pays annual income for the first M years regardless of survival, then continues paying income thereafter until the death of the insured. Let p_n be the one-year survival probability at age n, and let N be the maximum attainable age according to the appropriate mortality table. We define the actuarial value of a life annuity with an M-year guarantee at age n per dollar income as

$$V_t(n, M) = \sum_{m=1}^{M} \frac{1}{R_t(m)^m} + \sum_{m=M+1}^{N-n} \frac{\prod_{l=0}^{m-1} p_{n+l}}{R_t(m)^m}. \tag{2}$$

We calculate the actuarial value for life annuities based on the appropriate mortality table from the American Society of Actuaries and the zero-coupon Treasury yield curve. We use the 1983 Annuity Mortality Basic Table prior to January 1999 and the 2000 Annuity Mortality Basic Table since January 1999. These mortality tables are derived from the actual mortality experience of insured pools, based on data provided by various insurance companies. Therefore, they account for adverse selection in annuity markets, that is, an insured pool of annuitants has higher life expectancy than the overall population. We smooth the transition between the two vintages of the mortality tables by geometrically averaging.

1.1.2. Life Insurance Prices

Our sample of life insurance prices is from Compulife Software (2005–2011), which is a computer-based quotation system for insurance agents. We focus on guaranteed universal life policies, which are quoted for the leading life insurers since January 2005. These policies have constant guaranteed premiums and accumulate no cash value, so they are essentially "permanent" term life policies.[1] We pull quotes for the regular health category at the face amount of $250,000 in California. Compulife recommended California for our study because

[1] Although Compulife has quotes for various types of policies from annual renewable to 30-year term life policies, they are not useful for our purposes. A term life policy typically has a renewal option at the end of the guaranteed term. Because the premiums under the renewal option vary significantly across insurance companies, cross-sectional price comparisons are difficult and imprecise.

it is the most populous state with a wide representation of insurance companies. We focus on males and females aged 30 to 80 (every 10 years in between).

Universal life insurance pays out a death benefit upon the death of the insured. The policy is in effect as long as the policyholder makes an annual premium payment while the insured is alive. We define the actuarial value of universal life insurance at age n per dollar of death benefit as

$$V_t(n) = \left(1 + \sum_{m=1}^{N-n-1} \frac{\prod_{l=0}^{m-1} p_{n+l}}{R_t(m)^m}\right)^{-1} \left(\sum_{m=1}^{N-n} \frac{\prod_{l=0}^{m-2} p_{n+l}(1 - p_{n+m-1})}{R_t(m)^m}\right). \tag{3}$$

This formula does not account for the potential lapsation of policies, that is, the policyholder may drop coverage prior to the death of the insured. There is currently no agreed-upon standard for lapsation pricing, partly because lapsations are difficult to model and predict. Although some insurance companies price in low levels of lapsation, others take the conservative approach of assuming no lapsation in life insurance valuation.

We calculate the actuarial value for life insurance based on the appropriate mortality table from the American Society of Actuaries and the zero-coupon Treasury yield curve. We use the 2001 Valuation Basic Table prior to January 2008, and the 2008 Valuation Basic Table since January 2008. These mortality tables are derived from the actual mortality experience of insured pools, so they account for adverse selection in life insurance markets. We smooth the transition between the two vintages of the mortality tables by geometrically averaging.

1.1.3. Financial Statements and Ratings Information

The insurance companies' annual financial statements and ratings information are from A.M. Best Company (1993–2012a) for fiscal years 1992 to 2011, which is merged with A.M. Best Company (2012b) for fiscal years 2001 to 2011. These financial statements are prepared according to the statutory accounting principles and filed with the National Association of

Insurance Commissioners. Throughout the paper, we use an adjusted measure of capital and surplus (i.e., reported capital and surplus plus asset valuation reserve and conditional reserves), which is the relevant measure of accounting equity for risk-based capital (A.M. Best Company 2004, p. 11). We merge annuity and life insurance prices to the A.M. Best data by company name. The insurance price observed in a given fiscal year is matched to the financial statement at the end of that fiscal year.

Due to the limited availability of historical data on annuity and life insurance prices, our sample is limited to those companies that are covered by the WebAnnuities Insurance Agency and Compulife Software, which are essentially the largest companies with an A.M. Best rating of A− or higher. Table 1 reports that our sample covers 58 of 306 eligible companies in 2008, which represent 59 percent of the immediate annuity market and 57 percent of the life insurance market.

1.2. Summary Statistics

Table 2 summarizes our data on annuity and life insurance prices. We have 852 semiannual observations on 10-year term annuities from January 1989 to July 2011. The average markup, defined as the percent deviation of the quoted price from actuarial value, is 7.0 percent. Since term annuities are essentially straight bonds, we can rule out adverse selection as a source of this markup. Instead, the markup must be attributed to marketing and administrative costs as well as economic profits that may arise from imperfect competition. The fact that the average markup falls in the maturity of the term annuity is consistent with the presence of fixed costs. There is considerable variation in the pricing of 10-year term annuities across insurance companies, summarized by a standard deviation of 4.3 percent (Mitchell et al. 1999, find similar variation for life annuities).

We have 12,121 monthly observations on life annuities from January 1989 to July 2011. The average markup is 8.3 percent with a standard deviation of 7.6 percent. Our data on life annuities with guarantees start in May 1998. For 10-year guaranteed annuities, the average markup is 4.6 percent with a standard deviation of 6.6 percent. For 20-year guaranteed annuities, the average markup is 4.5 percent with a standard deviation of 6.5 percent.

We have 20,542 monthly observations on universal life insurance from January 2005 to July 2011. The average markup is −5.6 percent with a standard deviation of 16.0 percent. The negative average markup does not mean that insurance companies lose money on these policies. With a constant premium and a rising mortality rate, policyholders are essentially prepaying for coverage later in life. When a life insurance policy is lapsed, the insurance company earns a windfall profit because the present value of the remaining premium payments is typically less than the present value of the future death benefit. Since there is currently no agreed-upon standard for lapsation pricing, our calculation of actuarial value does not account for lapsation. We are not especially concerned that the average markup might be slightly mismeasured because the focus of our study is the variation in markups over time and across policies of different maturities.

1.3. Fire Sale of Insurance Policies

Figure 1 reports the time series of the average markup on term annuities at various maturities, averaged across insurance companies and reported with a 95 percent confidence interval. The average markup ordinarily varies between 0 and 10 percent, except around November 2008. The time-series variation in the average markup implies that insurance companies do not change annuity prices to perfectly offset interest rate movements (Charupat, Kamstra and Milevsky 2012).

For 30-year term annuities, the average markup fell to an extraordinary −15.7 percent in November 2008. Much of this large negative markup arises from reductions in the price of 30-year term annuities from May 2007 to November 2008. For example, Allianz Life Insurance Company of North America reduced the price of 30-year term annuities from \$18.56 (per dollar of annual income) in July 2007 to \$13.75 in December 2008, then raised it back up to \$18.23 by May 2009. Such price reductions cannot be explained by interest rate movements because relatively low Treasury yields implied a relatively high actuarial value for 30-year term annuities in November 2008.

In November 2008, the magnitude of the average markup is monotonically related to the maturity of the term annuity. The average markup was -8.5 percent for 20-year, -4.0 percent for 10-year, and -1.1 percent for 5-year term annuities. Excluding the extraordinary period around November 2008, the average markup was negative for 30-year term annuities only twice before in our semiannual sample, in October 2000 and October 2001.

Figure 2 reports the time series of the average markup on life annuities for males at various ages. Our findings are similar to that for term annuities. For life annuities at age 60, the average markup fell to an extraordinary -19.2 percent in December 2008. The magnitude of the average markup is monotonically related to age, which is negatively related to effective maturity. The average markup on life annuities was -14.9 percent at age 65, -10.5 percent at age 70, and -5.9 percent at age 75.[2]

Figure 3 reports the time series of the average markup on universal life insurance for males at various ages. Our findings are similar to that for term and life annuities. For universal life insurance at age 30, the average markup fell to an extraordinary -57.1 in December 2008. The magnitude of the average markup is monotonically related to age. The average markup on universal life insurance was -50.5 percent at age 40, -42.8 percent at age 50, and -27.7 percent at age 60.

Figure 4 shows that in the cross section of insurance companies, the price reductions were larger for those companies that suffered larger balance sheet shocks. For example, Allianz lost 3 percent of its assets in 2008, which led to a leverage ratio of 97 percent and a 35 percentage point deficit in its risk-based capital (relative to the A.M. Best guideline of 145 percent for its A rating). An important source of the shock was their deferred annuity liabilities (that amounted to 28 times their capital and surplus at fiscal year-end 2008), whose guarantees

[2] In Appendix D, we estimate the average markup on life annuities relative to an alternative measure of actuarial value based on the U.S. agency yield curve. We find that the average markups remain negative in December 2008, under this conservative adjustment for the special status of Treasury bonds as collateral in financial transactions.

were unprofitable during the financial crisis. In response to the shock, Allianz reduced the price of 20-year term annuities by 17.6 percent and life annuities for males aged 60 by 18.5 percent from May 2007 to November 2008. Starting with the evidence in Figures 1 to 4, the rest of the paper builds the case that financial frictions explain the fire sale of policies during the financial crisis.

2. Statutory Reserve Regulation for Life Insurers

When an insurance company sells an annuity or life insurance policy, its assets increase by the purchase price of the policy. At the same time, the insurance company must record statutory reserves on the liability side of its balance sheet to cover future policy claims. In the United States, the amount of required reserves for each type of policy is governed by state law, but all states essentially follow recommended guidelines known as Standard Valuation Law (National Association of Insurance Commissioners 2011, Appendix A-820). Standard Valuation Law establishes mortality tables and discount rates that are to be used for reserve valuation.

In this section, we review the reserve valuation rules for annuities and life insurance. Because these policies essentially have no exposure to market risk, finance theory implies that the market value of these policies is determined by the term structure of riskless interest rates. However, Standard Valuation Law requires that the reserve value of these policies be calculated using a mechanical discount rate that is a function of the Moody's composite yield on seasoned corporate bonds.[3] Insurance companies care about the reserve value of policies insofar as it is used by rating agencies and state regulators to determine the adequacy of statutory reserves (A.M. Best Company 2011, p. 31). A rating agency may downgrade an insurance company whose asset value has fallen relative to its statutory reserves.[4] In

[3]The same discount rate is used for financial reporting at the holding company level, prepared according to generally accepted accounting principles (GAAP). The key difference of GAAP, compared to statutory accounting principles, is the deferral and amortization of initial acquisition costs, which tends to increase reported equity (Lombardi 2006, pp. 4–7).

[4]For example, A.M. Best Company (2009) reports that MetLife's "financial leverage is at the high end of

the extreme case, the state regulator may liquidate an insurance company whose assets are deficient relative to its statutory reserves.

2.1. Term Annuities

Let y_t be the 12-month moving average of the Moody's composite yield on seasoned corporate bonds, over the period ending on June 30 of the issuance year of the policy. For an annuity issued in month t, Standard Valuation Law specifies the following discount rate for reserve valuation:

$$\widehat{R}_t - 1 = 0.03 + 0.8(y_t - 0.03), \tag{4}$$

which is rounded to the nearest 25 basis point. This a constant discount rate that applies to all expected policy claims, regardless of maturity. The exogenous variation in required reserves that this mechanical rule generates, both over time and across policies of different maturities, will allow us to identify the shadow cost of financial frictions.

Figure 5 reports the time series of the discount rate for annuities, together with the 10-year zero-coupon Treasury yield. The discount rate for annuities has generally fallen over the last 20 years as nominal interest rates have fallen. However, the discount rate for annuities has fallen more slowly than the 10-year Treasury yield. This means that statutory reserve requirements for annuities have become looser over time because a high discount rate implies low reserve valuation.

The reserve value of an M-year term annuity per dollar of income is

$$\widehat{V}_t(M) = \sum_{m=1}^{M} \frac{1}{\widehat{R}_t^m}. \tag{5}$$

Figure 6 reports the ratio of reserve to actuarial value for term annuities (i.e., $\widehat{V}_t(M)/V_t(M)$) at maturities of 5 to 30 years. Whenever this ratio is equal to one, the insurance company is

its threshold for the current rating level" at fiscal year-end 2008.

marking to market, that is, recording a dollar of reserve per dollar of future policy claims in present value. Whenever this ratio is above one, the reserve valuation is conservative in the sense that the recorded reserves are greater than the present value of future policy claims. Conversely, whenever this ratio is below one, the reserve valuation is aggressive in the sense that the recorded reserves are less than the present value of future policy claims.

For 30-year term annuities, the ratio of reserve to actuarial value reaches a peak of 1.20 in November 1994 and a trough of 0.73 in January 2009. If an insurance company were to sell a 30-year term annuity at actuarial value in November 1994, its reserves would increase by $1.20 per dollar of policies sold. This implies a loss of $0.20 in capital and surplus (i.e., accounting equity) per dollar of policies sold. In contrast, if an insurance company were to sell a 30-year term annuity at actuarial value in January 2009, its reserves would only increase by $0.73 per dollar of policies sold. This implies a gain of $0.27 in capital and surplus per dollar of policies sold.

2.2. Life Annuities

The reserve valuation of life annuities requires mortality tables. The American Society of Actuaries produces two versions of mortality tables, which are called basic and loaded. The loaded tables, which are used for reserve valuation, are conservative versions of the basic tables that underestimate the mortality rates. The loaded tables ensure that insurance companies have adequate reserves, even if actual mortality rates turn out to be lower than those projected by the basic tables. For calculating the reserve value, we use the 1983 Annuity Mortality Table prior to January 1999, and the 2000 Annuity Mortality Table since January 1999.

Let $\widehat{p}_n$ be the one-year survival probability at age n, and let N be the maximum attainable age according to the appropriate loaded mortality table. The reserve value of a life annuity with an M-year guarantee at age n per dollar of income (Lombardi 2006, p. 204) is

$$\widehat{V}_t(n, M) = \sum_{m=1}^{M} \frac{1}{\widehat{R}_t^m} + \sum_{m=M+1}^{N-n} \frac{\prod_{l=0}^{m-1} \widehat{p}_{n+l}}{\widehat{R}_t^m}, \tag{6}$$

where the discount rate is given by equation (4).

Figure 6 reports the ratio of reserve to actuarial value for life annuities, 10-year guaranteed annuities, and 20-year guaranteed annuities for males aged 50 to 80 (every 10 years in between). The time-series variation in reserve to actuarial value for life annuities is quite similar to that for term annuities. In particular, the ratio reaches a peak in November 1994 and a trough in January 2009. Since the reserve valuation of term annuities depends only on the discount rates, the similarity with term annuities implies that discount rates, rather than mortality tables, have a predominant effect on the reserve valuation of life annuities.

2.3. Life Insurance

Let y_t be the minimum of the 12-month and the 36-month moving average of the Moody's composite yield on seasoned corporate bonds, over the period ending on June 30 of the year prior to issuance of the policy. For life insurance with guaranteed term greater than 20 years issued in month t, Standard Valuation Law specifies the following discount rate for reserve valuation:

$$\widehat{R}_t - 1 = 0.03 + 0.35(\min\{y_t, 0.09\} - 0.03) + 0.175(\max\{y_t, 0.09\} - 0.09), \tag{7}$$

which is rounded to the nearest 25 basis point.

As with life annuities, the American Society of Actuaries produces basic and loaded mortality tables for life insurance. The loaded tables, which are used for reserve valuation, are conservative versions of the basic tables that overestimate the mortality rates. For calculating the reserve value, we use the 2001 Commissioners Standard Ordinary Mortality Table. The reserve value of life insurance at age n per dollar of death benefit (Lombardi 2006, pp. 67–68) is

$$\widehat{V}_t(n) = \left(1 + \sum_{m=1}^{N-n-1} \frac{\prod_{l=0}^{m-1} \widehat{p}_{n+l}}{\widehat{R}_t^m}\right)^{-1} \left(\sum_{m=1}^{N-n} \frac{\prod_{l=0}^{m-2} \widehat{p}_{n+l}(1-\widehat{p}_{n+m-1})}{\widehat{R}_t^m}\right) - \frac{1-\widehat{p}_n}{\widehat{R}_t}. \tag{8}$$

Figure 6 reports the ratio of reserve to actuarial value for universal life insurance for males aged 30 to 60 (every 10 years in between). Our earlier caveat regarding lapsation applies to this figure as well, so that we focus on the variation in reserve to actuarial value over time and across policies of different maturities. The reserve value falls significantly relative to actuarial value around December 2008. As shown in Figure 5, this is caused by the fact that the discount rate for life insurance stays constant during this period, while the 10-year Treasury yield falls significantly. If an insurance company were to sell universal life insurance to a 30-year-old male in December 2008, its reserves would only increase by \$0.69 per dollar of policies sold. This implies a gain of \$0.31 in capital and surplus per dollar of policies sold.

3. A Structural Model of Insurance Pricing

We now develop a model in which an insurance company sets prices for various types of policies to maximize the present value of profits, subject to a leverage constraint on the value of its assets relative to statutory reserves. The model shows how financial frictions and statutory reserve regulation jointly determine insurance prices.

3.1. An Insurance Company's Maximization Problem

An insurance company sells I different types of annuity and life insurance policies, which we index as $i = 1, \ldots, I$. These policies are differentiated not only by maturity but also by sex and age of the insured. The insurance company faces a downward-sloping demand curve $Q_{i,t}(P)$ for each policy i in period t (i.e., $Q'_{i,t}(P) < 0$). For now, we take the demand curve as exogenously given because its microfoundations are not essential for our immediate purposes. In Appendix A, we derive such a demand curve from first principles in a fully specified model with equilibrium price dispersion, arising from consumers that face search frictions.

Let $V_{i,t}$ be the actuarial value (or the marginal cost) of policy i in period t. The insurance company incurs a fixed (marketing and administrative) cost C_t in each period. The insurance company's profit in each period is

$$\Pi_t = \sum_{i=1}^{I} (P_{i,t} - V_{i,t}) Q_{i,t} - C_t. \tag{9}$$

A simple way to interpret this profit function is that for each type of policy that the insurance company sells for $P_{i,t}$, it can buy a portfolio of Treasury bonds that replicate its expected policy claims for $V_{i,t}$. For term annuities, this interpretation is exact since future policy claims are deterministic. For life annuities and life insurance, we assume that the insured pools are sufficiently large for the law of large numbers to apply.

We now describe how the sale of new policies affects the insurance company's balance sheet. Let A_{t-1} be its assets at the beginning of period t, and let $R_{A,t}$ be an exogenous rate of return on its assets in period t. Its assets at the end of period t, after the sale of new policies, is

$$A_t = R_{A,t} A_{t-1} + \sum_{i=1}^{I} P_{i,t} Q_{i,t} - C_t. \tag{10}$$

As explained in Section 2, the insurance company must also record reserves on the liability side of its balance sheet. Let L_{t-1} be its statutory reserves at the beginning of period t, and let $R_{L,t}$ be the return on its statutory reserves in period t. Let $\widehat{V}_{i,t}$ be the reserve value of policy i in period t. Its statutory reserves at the end of period t, after the sale of new policies, is

$$L_t = R_{L,t}L_{t-1} + \sum_{i=1}^{I} \widehat{V}_{i,t}Q_{i,t}. \tag{11}$$

The insurance company chooses the price $P_{i,t}$ for each type of policy to maximize firm value, or the present value of profits:

$$J_t = \Pi_t + \mathbf{E}_t[M_{t+1}J_{t+1}], \tag{12}$$

where M_{t+1} is the stochastic discount factor. The insurance company faces a leverage constraint on its statutory capital, or the value of its assets relative to statutory reserves:

$$K_t = A_t - \phi^{-1}L_t \geq 0, \tag{13}$$

where $\phi \leq 1$ is the maximum leverage ratio. Equations (10) and (11) imply that the law of motion for statutory capital is

$$K_t = R_{A,t}A_{t-1} - \phi^{-1}R_{L,t}L_{t-1} + \sum_{i=1}^{I} \left(P_{i,t} - \phi^{-1}\widehat{V}_{i,t}\right) Q_{i,t} - C_t. \tag{14}$$

The leverage constraint captures the notion that many highly rated insurance companies were concerned about a rating downgrade during the financial crisis, which would have an adverse impact on their business. At a deeper level, insurance companies are rated and regulated because of the potential for excessive risk taking (i.e., moral hazard) that may arise for various reasons. The leverage constraint can also be motivated as a simple version of a risk-based capital requirement:

$$\frac{A_t - L_t}{\rho L_t} \geq \psi, \tag{15}$$

where ρ is the risk charge and ψ is the guideline for a rating or regulatory action.[5] Equations (13) and (15) are equivalent by setting $\phi^{-1} = 1 + \rho\psi$. We model the capital requirement as a hard constraint, rather than a continuous cost, based on the evidence in Figure 4 that the pricing behavior is nonlinear in the leverage ratio and risk-based capital. In Appendix B, however, we show that an alternative model in which the insurance company faces a continuous cost has the same implications for pricing as the present model with a hard constraint.

3.2. *Optimal Insurance Pricing*

Let $\lambda_t \geq 0$ be the Lagrange multiplier on the leverage constraint (13). The Lagrangian for the insurance company's maximization problem is

$$\mathcal{L}_t = J_t + \lambda_t K_t. \tag{16}$$

The first-order condition for the price of each type of policy is

$$\begin{aligned} \frac{\partial \mathcal{L}_t}{\partial P_{i,t}} =& \frac{\partial J_t}{\partial P_{i,t}} + \lambda_t \frac{\partial K_t}{\partial P_{i,t}} = \frac{\partial \Pi_t}{\partial P_{i,t}} + \overline{\lambda}_t \frac{\partial K_t}{\partial P_{i,t}} \\ =& Q_{i,t} + (P_{i,t} - V_{i,t}) Q'_{i,t} + \overline{\lambda}_t \left[Q_{i,t} + \left(P_{i,t} - \phi^{-1} \widehat{V}_{i,t} \right) Q'_{i,t} \right] = 0, \end{aligned} \tag{17}$$

where

$$\overline{\lambda}_t = \lambda_t + \mathbf{E}_t \left[M_{t+1} \frac{\partial J_{t+1}}{\partial K_t} \right]. \tag{18}$$

Equation (17) implies that $\overline{\lambda}_t = -\partial \Pi_t / \partial K_t$. That is, $\overline{\lambda}_t$ measures the marginal reduction in profits that the insurance company is willing to accept in order to raise its statutory capital by a dollar. Equation (18) implies that $\overline{\lambda}_t = 0$ if the leverage constraint does not bind today (i.e., $\lambda_t = 0$), and increasing statutory capital does not relax future constraints

[5] For example, A.M. Best Company (2004) specifies $\rho \in [0.75\%, 3.5\%]$ for interest rate risk on general account annuities and $\psi = 160\%$ as the guideline for an A+ rating.

(i.e., $\mathbf{E}_t[M_{t+1}\partial J_{t+1}/\partial K_t] = 0$). Therefore, we refer to $\overline{\lambda}_t$ as the shadow cost of financial frictions because it measures the importance of the leverage constraint, either today or at some future state.

Rearranging equation (17), the price of policy i in period t is

$$P_{i,t} = V_{i,t}\left(1-\frac{1}{\epsilon_{i,t}}\right)^{-1}\left(\frac{1+\overline{\lambda}_t\phi^{-1}\left(\widehat{V}_{i,t}/V_{i,t}\right)}{1+\overline{\lambda}_t}\right), \tag{19}$$

where

$$\epsilon_{i,t} = -\frac{P_{i,t}Q'_{i,t}}{Q_{i,t}} > 1 \tag{20}$$

is the elasticity of demand. If the shadow cost is zero (i.e., $\overline{\lambda}_t = 0$), the price of policy i in period t is

$$\overline{P}_{i,t} = V_{i,t}\left(1-\frac{1}{\epsilon_{i,t}}\right)^{-1}. \tag{21}$$

This is the standard Bertrand formula of pricing, in which price is equal to marginal cost times a markup that is decreasing in the elasticity of demand.

If the shadow cost is positive (i.e., $\overline{\lambda}_t > 0$), the price of policy i in period t satisfies the inequality

$$P_{i,t} \gtrless \overline{P}_{i,t} \text{ if } \frac{\widehat{V}_{i,t}}{V_{i,t}} \gtrless \phi. \tag{22}$$

That is, the price of the policy is higher than the Bertrand price if selling the policy tightens the leverage constraint on the margin. This is the case with property and casualty insurers (Gron 1994), whose statutory reserve regulation requires that $\widehat{V}_{i,t}/V_{i,t} > 1$ (Teufel 2000). Conversely, the price of the policy is lower than the Bertrand price if selling the policy relaxes the leverage constraint on the margin. This was the case with life insurers around

December 2008, as shown in Figure 6.

When the leverage constraint (13) binds, equation (19) and the leverage constraint form a system of $I+1$ equations in $I+1$ unknowns (i.e., $P_{i,t}$ for each policy $i = 1, \ldots, I$ and $\overline{\lambda}_t$). Solving this system of equations for the shadow cost,

$$\overline{\lambda}_t = \frac{\sum_{i=1}^{I} \left(V_{i,t}(1 - 1/\epsilon_{i,t})^{-1} - \phi^{-1}\widehat{V}_{i,t} \right) Q_{i,t} + R_{A,t}A_{t-1} - \phi^{-1}R_{L,t}L_{t-1} - C_t}{-\sum_{i=1}^{I} \phi^{-1}\widehat{V}_{i,t}(\epsilon_{i,t} - 1)^{-1}Q_{i,t} - (R_{A,t}A_{t-1} - \phi^{-1}R_{L,t}L_{t-1} - C_t)}. \qquad (23)$$

3.3. Empirical Predictions

The pricing model (19) has key predictions for the cross section of policies and insurance companies that are consistent with the evidence in Section 1. In the cross section of policies, the model predicts that the price reductions are larger for those policies with looser statutory reserve requirements (i.e., lower $\widehat{V}_{i,t}/V_{i,t}$). Consistent with this prediction, Figures 1 to 3 show that the price reductions during the financial crisis align with the differences in reserve requirements across policies of different maturities in Figure 6. The model also explains why the fire sale of policies was so short-lived. Figure 6 shows that the reserve value was substantially lower than the actuarial value from November 2008 to February 2009, which was a relatively short window of opportunity for insurance companies to recapitalize through the sale of new policies. In the cross section of insurance companies, the model predicts that the price reductions are larger for more constrained companies (i.e., higher $\overline{\lambda}_t$). Consistent with this prediction, Figure 4 shows that the price reductions were larger for those companies that suffered larger balance sheet shocks.

4. Estimating the Structural Model of Insurance Pricing

We now estimate the shadow cost of financial frictions through the structural model of insurance pricing.

4.1. Empirical Specification

Let i index the type of policy, j index the insurance company, and t index time. The pricing model (19) implies a nonlinear regression model for the markup:

$$\log\left(\frac{P_{i,j,t}}{V_{i,t}}\right) = -\log\left(1 - \frac{1}{\epsilon_{i,j,t}}\right) + \log\left(\frac{1 + \overline{\lambda}_{j,t}(L_{j,t}/A_{j,t})^{-1}\left(\widehat{V}_{i,t}/V_{i,t}\right)}{1 + \overline{\lambda}_{j,t}}\right) + e_{i,j,t}, \tag{24}$$

where $e_{i,j,t}$ is an error term with conditional mean zero.

We model the elasticity of demand as

$$\epsilon_{i,j,t} = 1 + \exp\{-\beta' \mathbf{y}_{i,j,t}\}, \tag{25}$$

where $\mathbf{y}_{i,j,t}$ is a vector of insurance policy and company characteristics. In our baseline specification, the insurance policy characteristics are sex and age. The insurance company characteristics are the A.M. Best rating, log assets, asset growth, the leverage ratio, risk-based capital relative to guideline for the current rating, current liquidity, and the operating return on equity. We interact each of these variables with a dummy variable that allows their impact on the elasticity of demand to differ across annuities and life insurance. We also include dummy variables for year-month, to allow for time variation in the elasticity of demand (or preferences more generally), as well as domiciliary state.

In theory, the shadow cost of financial frictions depends only on insurance company characteristics that appear in equation (23). However, most of these characteristics do not have obvious counterparts in the data except for ϕ, which is equal to the leverage ratio when the leverage constraint (13) binds. Therefore, we model the shadow cost as

$$\overline{\lambda}_{j,t} = \exp\{-\gamma' \mathbf{z}_{j,t}\}, \tag{26}$$

where $\mathbf{z}_{j,t}$ is a vector of insurance company characteristics. Motivated by the reduced-form evidence in Figure 4, the insurance company characteristics are asset growth, the leverage ratio, and risk-based capital relative to guideline. We also include dummy variables for year-month to allow for time variation in the shadow cost.

4.2. Identifying Assumptions

If the elasticity of demand is correctly specified, the regression model (24) is identified by the fact that the markup has a nonnegative conditional mean in the absence of financial frictions (i.e., $-\log(1 - 1/\epsilon_{i,j,t}) > 0$). Therefore, a negative markup must be explained by a positive shadow cost whenever the ratio of reserve to actuarial value is less than the leverage ratio (i.e., $\widehat{V}_{i,t}/V_{i,t} < L_{j,t}/A_{j,t}$).

Even if the elasticity of demand is potentially misspecified, the shadow cost is identified by exogenous variation in reserve to actuarial value across different types of policies. To illustrate this point, we approximate the regression model (24) through a first-order Taylor approximation as

$$\log\left(\frac{P_{i,j,t}}{V_{i,t}}\right) \approx \alpha_{j,t} + \frac{1}{1 + 1/\overline{\lambda}_{j,t}}\left(\frac{\widehat{V}_{i,t}}{V_{i,t}} - \frac{L_{j,t}}{A_{j,t}}\right) + u_{i,j,t}, \tag{27}$$

where

$$u_{i,j,t} = -\alpha_{j,t} - \log\left(1 - \frac{1}{\epsilon_{i,j,t}}\right) + e_{i,j,t} \tag{28}$$

is an error term with conditional mean zero. For a given insurance company j at a given time t, the regression coefficient $\overline{\lambda}_{j,t}$ is identified by variation in $\widehat{V}_{i,t}/V_{i,t}$ across policies (indexed by i) that is orthogonal to $u_{i,j,t}$. More intuitively, Standard Valuation Law generates relative shifts in the supply curve across different types of policies that an insurance company sells, which we exploit to identify the shadow cost.

4.3. Estimating the Shadow Cost of Financial Frictions

Since the data for most types of annuities are not available prior to May 1998, we estimate the regression model (24) on the subsample from May 1998 to July 2011. Table 3 reports the estimated coefficients in the model for the elasticity of demand (i.e., β in equation (25)). The average markup on annuities sold by insurance companies rated A or A$-$ is 0.81 percentage points higher than that for annuities sold by companies rated A++ or A+. Asset growth, the leverage ratio, and risk-based capital relative to guideline have a relatively small economic impact on the markup through the elasticity of demand. For example, a one standard deviation increase in the leverage ratio is associated with a 0.42 percentage point increase in the markup.

Table 3 also reports the estimated coefficients in the model for the shadow cost of financial frictions (i.e., γ in equation (26)). The shadow cost is negatively related to asset growth and positively related to the leverage ratio. For example, a one standard deviation increase in the leverage ratio is associated with a 115 percent increase in the shadow cost. The shadow cost is also negatively related to risk-based capital relative to guideline, but its economic importance is two orders of magnitude smaller than that for asset growth and the leverage ratio.

Figure 7 reports the time series of the shadow cost for the average insurance company (i.e., at the mean of asset growth, the leverage ratio, and risk-based capital relative to guideline). The shadow cost is low for most of the sample, except around the 2001 recession and the recent financial crisis. Our point estimate of the shadow cost is \$2.32 per dollar of statutory capital from November 2008 to February 2009. That is, the average insurance company was willing to accept a marginal reduction of \$2.32 in profits in order to raise its statutory capital by a dollar. The 95 percent confidence interval for the shadow cost ranges from \$1.63 to \$3.30 per dollar of statutory capital.

Table 4 reports the shadow cost for the cross section of insurance companies in our sample that sold life annuities in November 2008. There is considerable heterogeneity in the shadow cost across insurance companies. MetLife was the most constrained company with a shadow cost of \$17.83 per dollar of statutory capital with a standard error of \$4.61. MetLife lost 9 percent of its assets in 2008, which led to a leverage ratio of 97 percent and a 26 percentage point deficit in its risk-based capital (relative to the A.M. Best guideline of 160 percent for its A+ rating). American General was the least constrained company with a shadow cost of \$0.76 per dollar of statutory capital, which is explained by the bailout of its holding company (American International Group) in September 2008, as we discuss below.

For the same set of insurance companies as in Table 4, Figure 8 reports the change in the quantity of immediate annuities issued from 2007 to 2009. The linear regression line reveals a strong positive relation between the change in annuities issued during the financial crisis and the shadow cost in November 2008. In particular, MetLife had both the highest increase in annuities issued (231 percent) and the highest shadow cost. This is consistent with the hypothesis that the supply curve shifts down for financially constrained companies, lowering equilibrium prices and raising equilibrium quantities.

4.4. Conventional Channels of Recapitalization

Since operating companies cannot directly issue public equity or debt, they essentially have three channels of improving their capital positions. The first, which we emphasize in this paper, is the sale of new policies at an accounting profit. The second is the reduction of required risk-based capital by shifting to safer assets with lower risk charges, such as cash and short-term investments (see Ellul et al. (2012) and Merrill et al. (2012) for related evidence). The third is a direct capital injection from its holding company, which can issue public equity or debt, or the reduction of stockholder dividends (see Berry-Stölzle, Nini and Wende (2012) for related evidence). We now show that these three channels were complementary during the financial crisis.

For the same set of insurance companies as in Table 4, the left panel of Figure 9 reports the change in cash and short-term investments in 2008 and 2009, as a percentage of capital and surplus at fiscal year-end 2007. The linear regression line reveals a strong positive relation between the change in cash and short-term investments and the shadow cost in November 2008. In particular, MetLife had both the highest increase in cash and short-term investments (134 percent) and the highest shadow cost.

For the same set of insurance companies as in Table 4, the right panel of Figure 9 reports the net equity inflow (i.e., capital and surplus paid in minus stockholder dividends) in 2008 and 2009, as a percentage of capital and surplus at fiscal year-end 2007. The linear regression line reveals a strong positive relation between the net equity inflow and the shadow cost in November 2008. In particular, MetLife had both the highest net equity inflow (251 percent) and the highest shadow cost. American General is an outlier with a relatively high net equity inflow (151 percent), despite having the lowest shadow cost, which is explained by the bailout of its holding company (American International Group).

Figure 10 shows the time series of the equity inflow from 2006 to 2010. MetLife and Allianz, which are two of the most constrained companies according to our estimates, had unusually high equity inflow in 2008 and 2009 compared to Genworth and American National, which are two of the least constrained companies. American General had high equity inflow in 2008, associated with the bailout, which was subsequently returned to the holding company in 2010. Figure 11, which shows the time series of stockholder dividends paid from 2006 to 2010, complements the evidence in Figure 10. MetLife and Allianz paid no dividends from 2007 to 2009, in contrast to Genworth and American National, which continued to pay dividends throughout the financial crisis.

The policyholders of an operating company are senior to the creditors of its holding company. Moreover, state regulators can severely restrict the movement of capital from an operating company to its holding company (A.M. Best Company 2011, p. 21). This "regulatory overhang" (in analogy to debt overhang) affects the incentives of a holding company to inject capital into an operating company, creating frictions in internal capital markets. These frictions explain why the capital injections from the holding company may have been limited, leading to a fire sale of policies by the operating company. Figure 10 illustrates this problem by showing the time series of ordinary dividends authorized, according to the Insurance Holding Company System Regulatory Act (National Association of Insurance Commissioners 2011, Appendix A-440). Due to its operating losses interacting with the regulation, MetLife was not authorized to pay ordinary dividends from 2006 to 2009. Therefore, the holding company faced the serious risk that any capital that it injects into the operating company may not be paid back as dividends, at least in the foreseeable future.

Although frictions in internal capital markets suffice to explain the fire sale of policies, it is certainly possible that they may have been exacerbated by frictions in external capital markets at the holding company level. In Appendix E, we examine MetLife's equity issuance on October 7, 2008, as a case study of how costly external financing might have been for life insurers during the financial crisis. The announcement effect of the equity issuance on the stock price is consistent with a large cost of external capital for the holding company. Although this announcement effect must be interpreted with caution for reasons discussed in the appendix, it is consistent with our estimates of the cost of internal capital for the operating company.

5. Ruling Out Alternative Hypotheses

We now rule out the theory of price wars and default risk as alternative hypotheses.

5.1. Theory of Price Wars

Our theory based on financial frictions explains the following empirical findings.

1. Insurance companies priced policies below marginal cost during the financial crisis (see Figures 1 to 3).

2. Insurance companies that suffered larger balance sheet shocks reduced prices more (see Figure 4).

3. The market share increased for those companies that reduced prices more (see Figure 8).

We consider three theories of price wars as alternative hypotheses for this evidence.

The first, which is widely used in industrial organization and macroeconomics, is based on collusion (e.g., Rotemberg and Saloner 1986). This theory predicts that price wars are more likely to occur in expansions because the gain to deviating from collusive behavior is greater when aggregate demand is higher. Moreover, this theory does not predict pricing below marginal cost because firms emphasize current profits over future profits when deviating from collusive behavior. Therefore, we rule out this theory because these two predictions contradict our first empirical finding.

The second theory of price wars is predatory pricing, in which a financially stronger company prices below marginal cost in order to push a weaker competitor out of business. We rule out this theory because it predicts the opposite of our second empirical finding that financially weaker companies reduced prices more. Moreover, this theory is typically dismissed because predatory pricing is illegal under antitrust laws, and this type of behavior is not individually rational unless the barriers to future entry are incredibly high.

The third theory of price wars is based on persistence in market shares that arise from frictions such as switching costs (e.g., Klemperer 1987). Firms may rationally reduce current prices, even below marginal cost, in order to capture future monopoly rents. In Appendix C, we develop a model of price wars based on this idea, by adopting Chevalier and Scharfstein (1996) to our context. This theory comes closest to explaining our empirical findings, by predicting pricing below marginal cost when aggregate demand is weak. However, this theory also predicts that the market share decreases for those companies that reduce prices more, which contradicts our third empirical finding. This theory also has ambiguous predictions for the cross-sectional relation between price reductions and leverage, so it does not provide a straightforward explanation for our second empirical finding.

We now highlight additional evidence in the paper that is either inconsistent or unrelated to the theory of price wars, but consistent with our theory based on financial frictions. First, the theory of price wars does not explain why the fire sale of policies disappeared after February 2009, or why insurance companies did not discount policies in other periods of weak demand, such as the 1991 recession or the Great Depression. Our theory, on the other hand, predicts the exact timing of when insurance companies discount policies. Equation (19) shows that a necessary condition for insurance companies to discount policies is that the ratio of reserve to actuarial value (i.e., $\widehat{V}_{i,t}/V_{i,t}$) is significantly below one. This condition was satisfied from November 2008 to February 2009 and in the 2001 recession, but not in the 1991 recession or the Great Depression.

Second, the theory of price wars does not explain why the discounts vary across policies of different maturities. One could reverse engineer separate demand shocks by maturity, in an attempt to fit the price war model to the data. However, such a model would be overparameterized and, therefore, difficult to falsify based on pricing data alone. In contrast, we offer a simpler explanation, that the discounts vary by maturity due to plausibly exogenous variation in reserve to actuarial value that arises from Standard Valuation Law. As explained in Section 4, our model is identified as long as misspecification in demand or competitive forces is not correlated with the variation in reserve to actuarial value across different types of policies.

Third, Figure 4 shows that price reductions in the cross section of insurance companies are strongly related to the amount of deferred (fixed and variable) annuity liabilities, whose guarantees were unprofitable during the financial crisis. Our view is that insurance companies with larger exposure to this source of aggregate risk became more constrained and, consequently, reduced prices in order to recapitalize. The theory of price wars does not explain why the amount of deferred annuity liabilities should be so closely related to price reductions.

Finally, the theory of price wars does not explain the evidence in Figures 9 to 11. That is, it does not explain why insurance companies with larger price reductions also reduced required risk-based capital by shifting to safer assets, received large capital injections from their holding companies, and reduced stockholder dividends. Our theory based on financial frictions is a more natural explanation for this extraordinary activity during the financial crisis.

5.2. Default Risk

Since policies are ultimately backed by the state guaranty fund (e.g., up to \$250k for annuities and \$300k for life insurance in California), the only scenario in which a policyholder would not be fully repaid is if all insurance companies associated with the state guaranty fund were to systemically fail. During the financial crisis, the pricing of annuities and life insurance remained linear around the guaranteed amount, and the pricing was uniform across states with different guaranty provisions. The absence of kinks in pricing around the guaranteed amount rules out idiosyncratic default risk that affects only some insurance companies, but it does not rule out systematic default risk in which the state guaranty fund fails.

Suppose we were to entertain an extreme scenario in which the state guaranty fund fails. Since life insurers are subject to risk-based capital regulation, risky assets (e.g., non-investment-grade bonds, common and preferred stocks, non-performing mortgages, and real estate) account for only 16 percent of their assets (Ellul, Jotikasthira and Lundblad 2011). The remainder of their assets are in safe asset classes such as cash, Treasury bonds, and investment-grade bonds. Under an extreme assumption that risky assets lose their value entirely, a reasonable lower bound on the recovery rate is 84 percent. To further justify this recovery rate, the asset deficiency in past cases of insolvency typically ranges from 5 to 10 percent and very rarely exceeds 15 percent (Gallanis 2009).

Let $d_t(l)$ be the risk-neutral default probability between year $l-1$ and l at time t, and let θ be the recovery rate conditional on default. Then the market value of an M-year term annuity per dollar of income is

$$V_t(M) = \sum_{m=1}^{M} \frac{\theta + (1-\theta)\prod_{l=1}^{m}(1-d_t(l))}{R_t(m)^m}. \tag{29}$$

Panel B of Table 5 reports the term structure of default probabilities implied by the markups on term annuities in Panel A. For MetLife, an annual default probability of 24.4 percent at the 1- to 5-year horizon and 17.9 percent at the 6- to 10-year horizon justifies the markups on 5- and 10-year term annuities. There are no default probabilities that can justify the discounts on term annuities with maturity greater than 15 years. This is because equation (29) implies that the discount cannot be greater than 16 percent (i.e., one minus the recovery rate), which is clearly violated for term annuities with maturity greater than 25 years.

Panel C of Table 5 presents further evidence against default risk based on the term structure of risk-neutral default probabilities implied by credit default swaps on the holding company of the respective operating company in Panel B. First, the 6- to 10-year default probability implied by term annuities is higher than that implied by credit default swaps for all insurance companies, except American General. This finding is inconsistent with default risk given that the policyholders of an operating company are senior to the creditors of its holding company. Second, term annuities imply an upward-sloping term structure of default probabilities, which does not match the downward-sloping term structure implied by credit default swaps. Finally, the relative ranking of default probabilities across the operating companies in Panel B does not align with the relative ranking across the respective holding companies in Panel C.

In Appendix G, we also find out-of-sample evidence against default risk based on the absence of discounts on life annuities during the Great Depression, when the corporate default spread was even higher than the heights reached during the recent financial crisis. Only our explanation, based on financial frictions and statutory reserve regulation, is consistent with the evidence for both the financial crisis and the Great Depression.

6. Conclusion

This paper shows that financial frictions and statutory reserve regulation have a large and measurable impact on insurance prices. More broadly, we show that frictions on the supply side have a large and measurable impact on consumer financial markets. The previous literature on household finance has mostly focused on frictions on the demand side of these markets, such as household borrowing constraints, asymmetric information, moral hazard, and near rationality. Although these frictions on the demand side are undoubtedly important, we believe that financial and regulatory frictions on the supply side are also important to our understanding of market equilibrium and welfare.

Another broader implication of our study is that we provide micro evidence for a class of macro models based on financial frictions, which is a leading explanation for the Great Recession (see Gertler and Kiyotaki (2010) and Brunnermeier, Eisenbach and Sannikov (2013) for recent surveys). We believe that this literature would benefit from additional micro evidence on the cost of these frictions for other types of financial institutions, such as commercial banks and health insurance companies. The empirical approach in this paper may be extended to estimate the shadow cost of financial frictions for other types of financial institutions.

References

A.M. Best Company, "Best's Insurance Reports: Life/Health, United States and Canada," 1993–2012.

____ , "Understanding BCAR for Life and Health Insurers," 2004.

____ , "MetLife Investors USA Insurance Company," in "Best's Insurance Reports: Life/Health, United States and Canada," Oldwick, NJ: A.M. Best Company, 2009.

____ , "Best's Credit Rating Methodology: Global Life and Non-Life Insurance Edition," 2011.

____ , "Best's Statement File: Life/Health, United States," 2012.

Berry-Stölzle, Thomas R., Gregory P. Nini, and Sabine Wende, "External Financing in the Life Insurance Industry: Evidence from the Financial Crisis," 2012. Unpublished.

Brunnermeier, Markus K. and Lasse Heje Pedersen, "Market Liquidity and Funding Liquidity," *Review of Financial Studies*, 2009, *22* (6), 2201–2238.

____ , Thomas M. Eisenbach, and Yuliy Sannikov, "Macroeconomics with Financial Frictions: A Survey," in Daron Acemoglu, Manuel Arellano, and Eddie Dekel, eds., *Advances in Economics and Econometrics: Tenth World Congress*, Vol. 2, Cambridge: Cambridge University Press, 2013, chapter 1.

Charupat, Narat, Mark Kamstra, and Moshe A. Milevsky, "The Annuity Duration Puzzle," 2012. Unpublished.

Chevalier, Judith A. and David S. Scharfstein, "Capital-Market Imperfections and Countercyclical Markups: Theory and Evidence," *American Economic Review*, 1996, *86* (4), 703–725.

Compulife Software, "Compulife Historical Data," 2005–2011.

Ellul, Andrew, Chotibhak Jotikasthira, and Christian T. Lundblad, "Regulatory Pressure and Fire Sales in the Corporate Bond Market," *Journal of Financial Economics*, 2011, *101* (3), 596–620.

____ , ____ , ____ , and Yihui Wang, "Is Historical Cost Accounting a Panacea? Market Stress, Incentive Distortions, and Gains Trading," 2012. Unpublished.

Froot, Kenneth A. and Paul G. J. O'Connell, "The Pricing of U.S. Catastrophe Reinsurance," in Kenneth A. Froot, ed., *The Financing of Catastrophe Risk*, Chicago: University of Chicago Press, 1999, chapter 5, pp. 195–232.

Gallanis, Peter G., "NOLHGA, the Life and Health Insurance Guaranty System, and the Financial Crisis of 2008–2009," 2009. National Organization of Life and Health Insurance Guaranty Associations.

Gertler, Mark and Nobuhiro Kiyotaki, "Financial Intermediation and Credit Policy in Business Cycle Analysis," in Benjamin M. Friedman and Michael Woodford, eds., *Handbook of Monetary Economics*, Vol. 3, Amsterdam: Elsevier, 2010, chapter 11, pp. 547–599.

Gron, Anne, "Evidence of Capacity Constraints in Insurance Markets," *Journal of Law and Economics*, 1994, *37* (2), 349–377.

Gürkaynak, Refet S., Brian Sack, and Jonathan H. Wright, "The U.S. Treasury Yield Curve: 1961 to the Present," *Journal of Monetary Economics*, 2007, *54* (8), 2291–2304.

Kiyotaki, Nobuhiro and John Moore, "Credit Cycles," *Journal of Political Economy*, 1997, *105* (2), 211–248.

Klemperer, Paul, "Markets with Consumer Switching Costs," *Quarterly Journal of Economics*, 1987, *102* (2), 375–394.

Lombardi, Louis J., *Valuation of Life Insurance Liabilities*, 4th ed., Winsted, CT: ACTEX Publications, 2006.

Merrill, Craig B., Taylor D. Nadauld, René M. Stulz, and Shane M. Sherlund, "Did Capital Requirements and Fair Value Accounting Spark Fire Sales in Distressed Mortgage-Backed Securities?," 2012. NBER Working Paper 18270.

Mitchell, Olivia S., James M. Poterba, Mark J. Warshawsky, and Jeffrey R. Brown, "New Evidence on the Money's Worth of Individual Annuities," *American Economic Review*, 1999, *89* (5), 1299–1318.

National Association of Insurance Commissioners, *Accounting Practices and Procedures Manual*, Kansas City, MO: National Association of Insurance Commissioners, 2011.

Rotemberg, Julio J. and Garth Saloner, "A Supergame-Theoretic Model of Price Wars during Booms," *American Economic Review*, 1986, *76* (3), 390–407.

Rothschild, Michael and Joseph E. Stiglitz, "Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information," *Quarterly Journal of Economics*, 1976, *90* (4), 630–649.

Stern, Hersh L., "Annuity Shopper," 1989–2011. WebAnnuities Insurance Agency.

——, "Comparative Annuity Reports," 2007–2009. WebAnnuities Insurance Agency.

Teufel, Patricia A., "P&C Actuarial Issues Associated with Implementation of NAIC Accounting Practices and Procedures," 2000. Committee on Property and Liability Financial Reporting of the American Academy of Actuaries.

Yaari, Menahem E., "Uncertain Lifetime, Life Insurance, and the Theory of the Consumer," *Review of Economic Studies*, 1965, *32* (2), 137–150.

Table 1: Market Share of the Sample of Life Insurers

	Number of insurance companies		Percent of market covered	
Year	Total	Covered	Immediate annuities	Life insurance
2001	359	71	56	
2002	344	69	57	
2003	334	69	57	
2004	319	69	46	
2005	318	69	51	57
2006	312	63	52	57
2007	312	59	51	57
2008	306	58	59	57
2009	292	55	61	57
2010	299	55	58	55
2011	296	55	58	58

Eligible companies are those with an A.M. Best rating of A− or higher, domiciled outside of New York. This table reports the total number of eligible companies by fiscal year and the subset of those companies that are covered by the WebAnnuities Insurance Agency and Compulife Software. It also reports the market share of the covered companies by total face value of individual immediate annuities and life insurance issued.

Table 2: Summary Statistics for Annuity and Life Insurance Prices

				Markup (percent)		
Type of policy	Sample begins	Frequency	Observations	Mean	Median	Standard deviation
Term annuities:						
5 years	December 1992	Semiannual	628	6.6	6.7	3.9
10 years	January 1989	Semiannual	852	7.0	7.2	4.3
15 years	May 1998	Semiannual	387	4.4	4.5	4.6
20 years	May 1998	Semiannual	383	4.1	4.0	5.7
25 years	May 1998	Semiannual	311	3.7	3.7	6.7
30 years	May 1998	Semiannual	302	3.2	2.9	7.9
Life annuities:						
Life only	January 1989	Monthly	12,121	8.3	8.8	7.6
10-year guarantee	May 1998	Monthly	8,917	4.6	5.2	6.6
20-year guarantee	May 1998	Semiannual	6,050	4.5	4.8	6.5
Universal life insurance	January 2005	Monthly	20,542	-5.6	-6.1	16.0

The markup is defined as the percent deviation of the quoted price from actuarial value. The actuarial value is based on the appropriate basic mortality table from the American Society of Actuaries and the zero-coupon Treasury yield curve. The sample covers life insurers with an A.M. Best rating of A− or higher from January 1989 to July 2011.

Table 3: Estimated Model of Insurance Pricing

Explanatory variable	Coefficient	
A.M. Best rating: A or A−	0.81	(0.10)
Log assets	0.63	(0.05)
Asset growth	0.12	(0.03)
Leverage ratio	0.42	(0.08)
Risk-based capital relative to guideline	-0.06	(0.03)
Current liquidity	0.41	(0.03)
Operating return on equity	0.35	(0.05)
Female	0.09	(0.05)
Age 50	0.29	(0.23)
Age 55	0.50	(0.19)
Age 60	0.61	(0.16)
Age 65	0.89	(0.17)
Age 70	1.30	(0.18)
Age 75	1.61	(0.18)
Age 80	1.76	(0.20)
Age 85	2.28	(0.28)
Interaction effects for life insurance:		
A.M. Best rating: A or A−	-15.62	(3.07)
Log assets	-15.11	(1.68)
Asset growth	-4.97	(0.65)
Leverage ratio	-0.68	(0.36)
Risk-based capital relative to guideline	-0.57	(0.20)
Current liquidity	-1.98	(0.53)
Operating return on equity	-3.22	(0.61)
Female	-0.16	(0.08)
Age 30	-31.59	(5.38)
Age 40	-32.95	(5.40)
Age 50	-32.77	(5.25)
Age 60	-32.60	(5.42)
Age 70	-32.24	(5.25)
Age 80	-31.76	(5.14)
Shadow cost (semi-elasticity):		
Asset growth	-79.64	(8.56)
Leverage ratio	115.03	(12.14)
Risk-based capital relative to guideline	-0.16	(0.08)
R^2 (percent)	31.54	
Observations	36,952	

This table reports the average marginal effect of the standardized explanatory variables on the markup through the elasticity of demand in percentage points. The specification for the elasticity of demand also includes dummy variables for year-month and domiciliary state, which are omitted in this table for brevity. The omitted categories for the dummy variables are term annuities, A.M. Best rating of A++ or A+, and male. This table also reports the semi-elasticity of the shadow cost of financial frictions with respect to the standardized explanatory variables in percentage points. The specification for the shadow cost also depends on dummy variables for year-month, which are omitted in this table for brevity. Robust standard errors, clustered by insurance company, type of policy, sex, and age, are reported in parentheses. The sample covers life insurers with an A.M. Best rating of A− or higher from May 1998 to July 2011.

Table 4: Shadow Cost of Financial Frictions in November 2008

Insurance company	A.M. Best rating	Shadow cost (dollars)	Asset growth (percent)	Leverage ratio (percent)	RBC relative to guideline (percent)
MetLife Investors USA Insurance	A+	17.83	-9	97	-26
		(4.61)			
Allianz Life Insurance of North America	A	12.60	-3	97	-35
		(3.01)			
Lincoln Benefit Life	A+	11.10	-37	87	-11
		(3.82)			
OM Financial Life Insurance	A	9.79	-4	95	-10
		(2.21)			
Kansas City Life Insurance	A	3.57	-8	89	58
		(0.77)			
Aviva Life and Annuity	A+	3.36	12	95	3
		(0.64)			
Integrity Life Insurance	A++	3.33	3	92	68
		(0.62)			
EquiTrust Life Insurance	A-	3.12	14	95	16
		(0.59)			
United of Omaha Life Insurance	A+	3.09	-3	90	72
		(0.62)			
Genworth Life Insurance	A+	2.50	0	90	2
		(0.48)			
American National Insurance	A+	1.25	-2	86	2
		(0.28)			
North American for Life and Health Insurance	A+	1.09	27	93	51
		(0.21)			
American General Life Insurance	A	0.76	6	85	-29
		(0.17)			

This table reports the shadow cost of financial frictions, implied by the estimated model of insurance pricing, for the cross section of insurance companies in our sample that sold life annuities in November 2008. Robust standard errors, based on the delta method, are reported in parentheses. The growth in total admitted assets is from fiscal year-end 2007 to 2008. The leverage ratio and risk-based capital (Best's Capital Adequacy Ratio) relative to guideline for the current rating are at fiscal year-end 2008.

Table 5: Default Probabilities Implied by Term Annuities versus Credit Default Swaps in November 2008

	Maturity (years)					
Insurance company	5	10	15	20	25	30
Panel A: Markup (percent)						
Allianz Life Insurance of North America	0.4	-2.9	-7.7	-12.8	-18.2	-21.7
Lincoln Benefit Life	-1.4	-4.6	-6.3	-7.8	-9.9	-12.6
MetLife Investors USA Insurance		-9.2	-12.1	-14.5	-17.3	-20.9
Genworth Life Insurance	0.0	-2.6	-4.0	-5.9	-8.7	-12.4
Aviva Life and Annuity	0.1	-1.5	-2.1	-4.3	-7.9	-11.9
American General Life Insurance	-2.4	-3.3	-4.6	-7.8	-10.6	-14.2
Panel B: Default probabilities implied by term annuities (percent annual)						
Allianz Life Insurance of North America	0.0	72.6	100.0	100.0	100.0	100.0
Lincoln Benefit Life	3.2	19.6	16.5	100.0	100.0	100.0
MetLife Investors USA Insurance	24.4	17.9	100.0	100.0	100.0	100.0
Genworth Life Insurance	0.1	15.4	14.5	100.0	100.0	100.0
Aviva Life and Annuity	0.0	8.4	10.1	100.0	100.0	100.0
American General Life Insurance	5.4	1.6	78.6	100.0	100.0	100.0
Panel C: Default probabilities implied by credit default swaps (percent annual)						
Allianz Life Insurance of North America	2.0	1.8				
Lincoln Benefit Life	4.5	3.7				
MetLife Investors USA Insurance	9.5	5.9				
Genworth Life Insurance	31.4	4.7				
Aviva Life and Annuity	3.0	2.9				
American General Life Insurance	19.4	7.6				

Panel B reports the term structure of risk-neutral default probabilities that justify the markups on term annuities in Panel A. An implied default probability of 100 percent means that the markups are too low to be justified by default risk, given a recovery rate of 84 percent. Panel C reports the term structure of risk-neutral default probabilities implied by 5- and 10-year credit default swaps on the holding company of the respective operating company in Panel B. Appendix F describes how we estimate the term structure of risk-neutral default probabilities from credit default swaps.

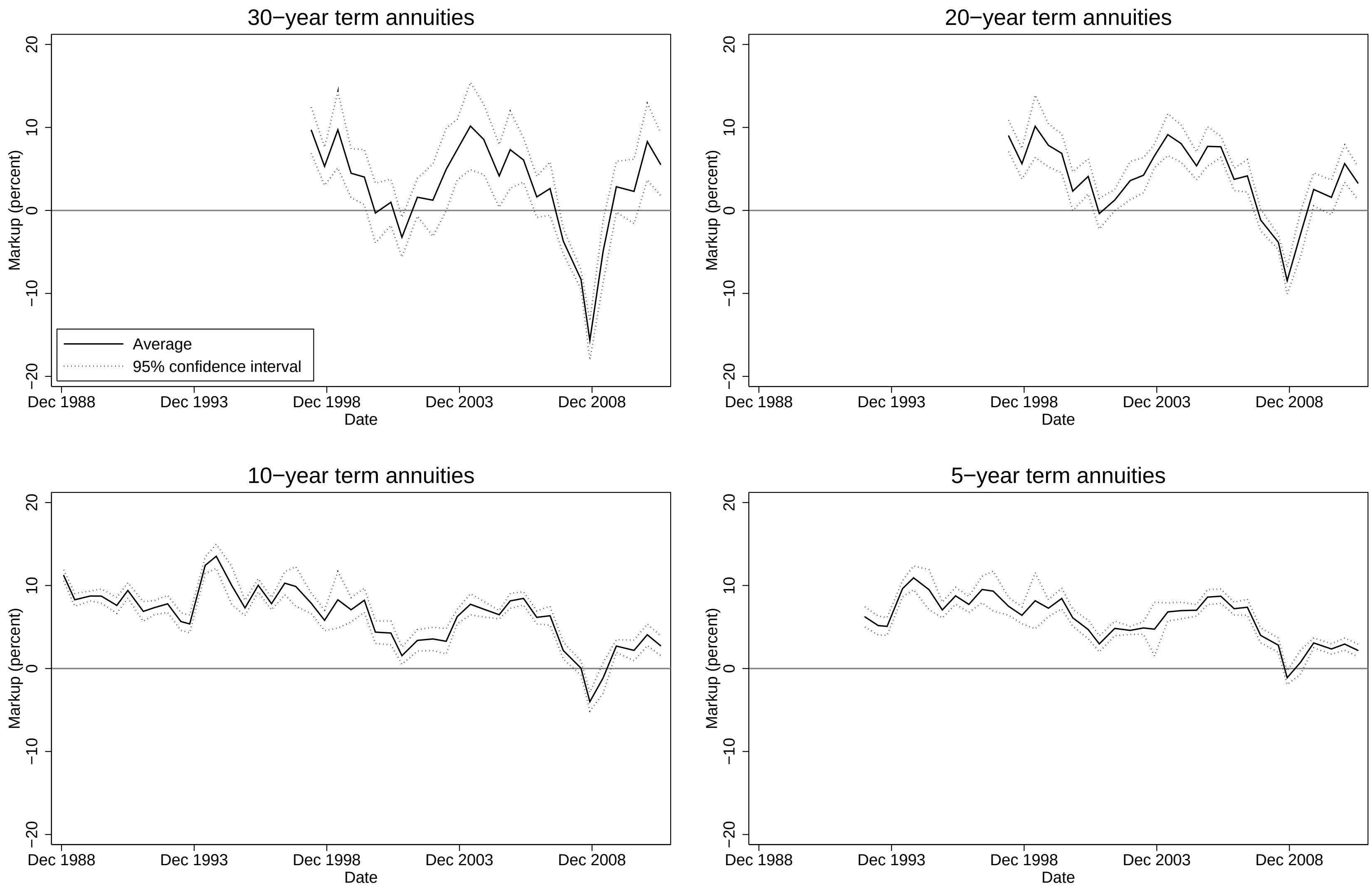

Figure 1: Average Markup on Term Annuities
The markup is defined as the percent deviation of the quoted price from actuarial value. The actuarial value is based on the zero-coupon Treasury yield curve. The sample covers life insurers with an A.M. Best rating of A− or higher from January 1989 to July 2011.

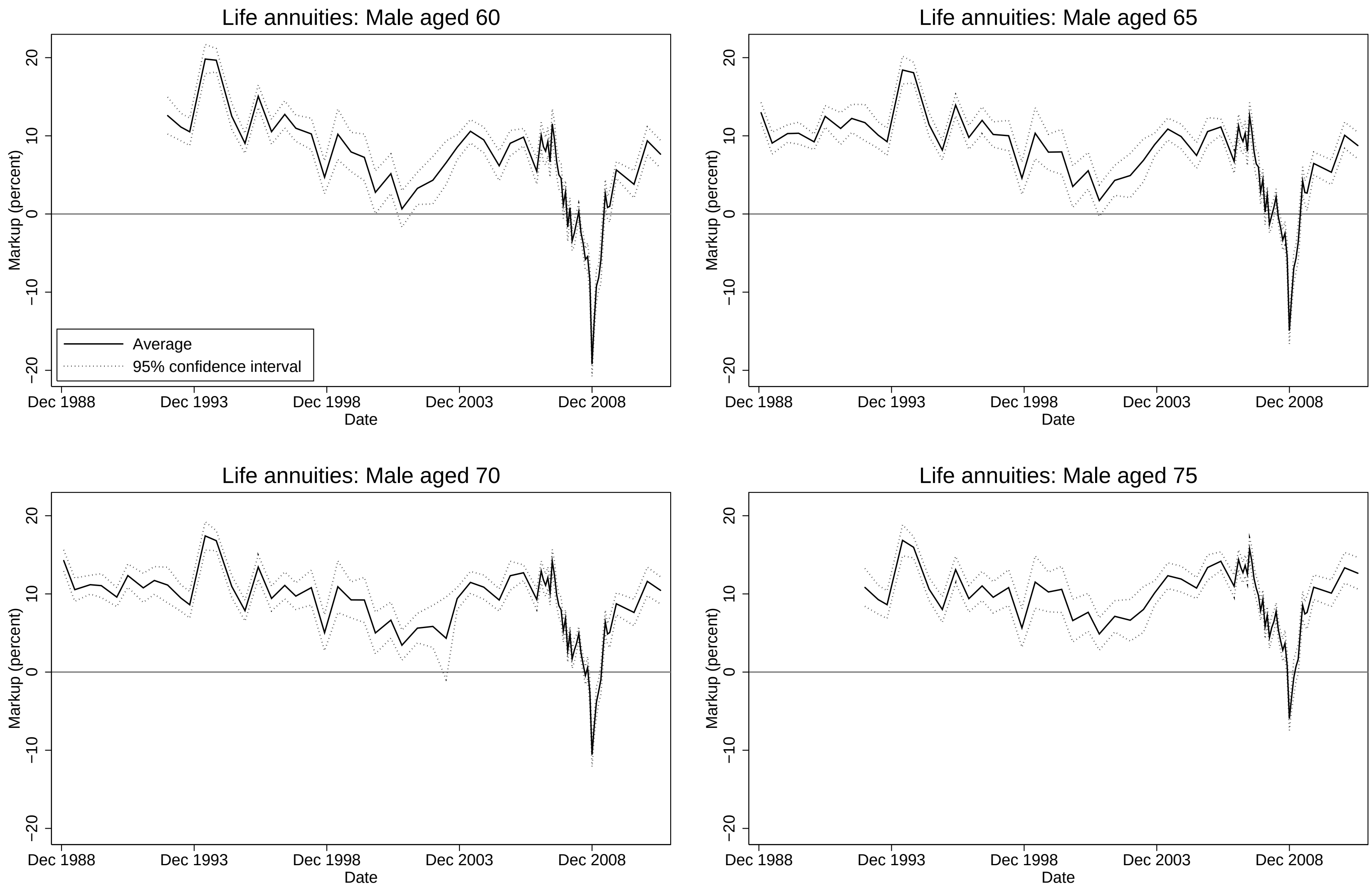

Figure 2: Average Markup on Life Annuities

The markup is defined as the percent deviation of the quoted price from actuarial value. The actuarial value is based on the appropriate basic mortality table from the American Society of Actuaries and the zero-coupon Treasury yield curve. The sample covers life insurers with an A.M. Best rating of A− or higher from January 1989 to July 2011.

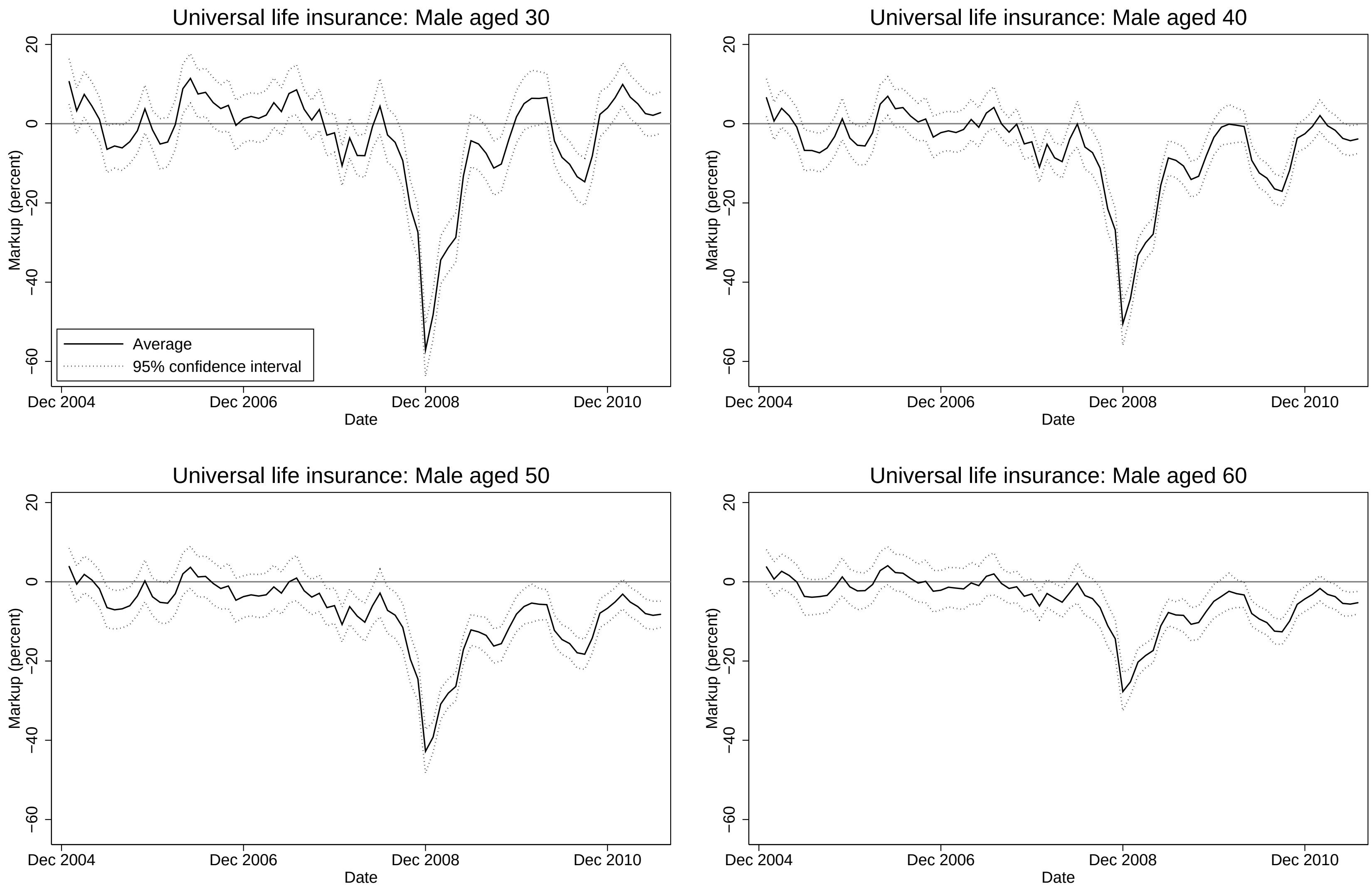

Figure 3: Average Markup on Life Insurance

The markup is defined as the percent deviation of the quoted price from actuarial value. The actuarial value is based on the appropriate basic mortality table from the American Society of Actuaries and the zero-coupon Treasury yield curve. The sample covers life insurers with an A.M. Best rating of A− or higher from January 2005 to July 2011.

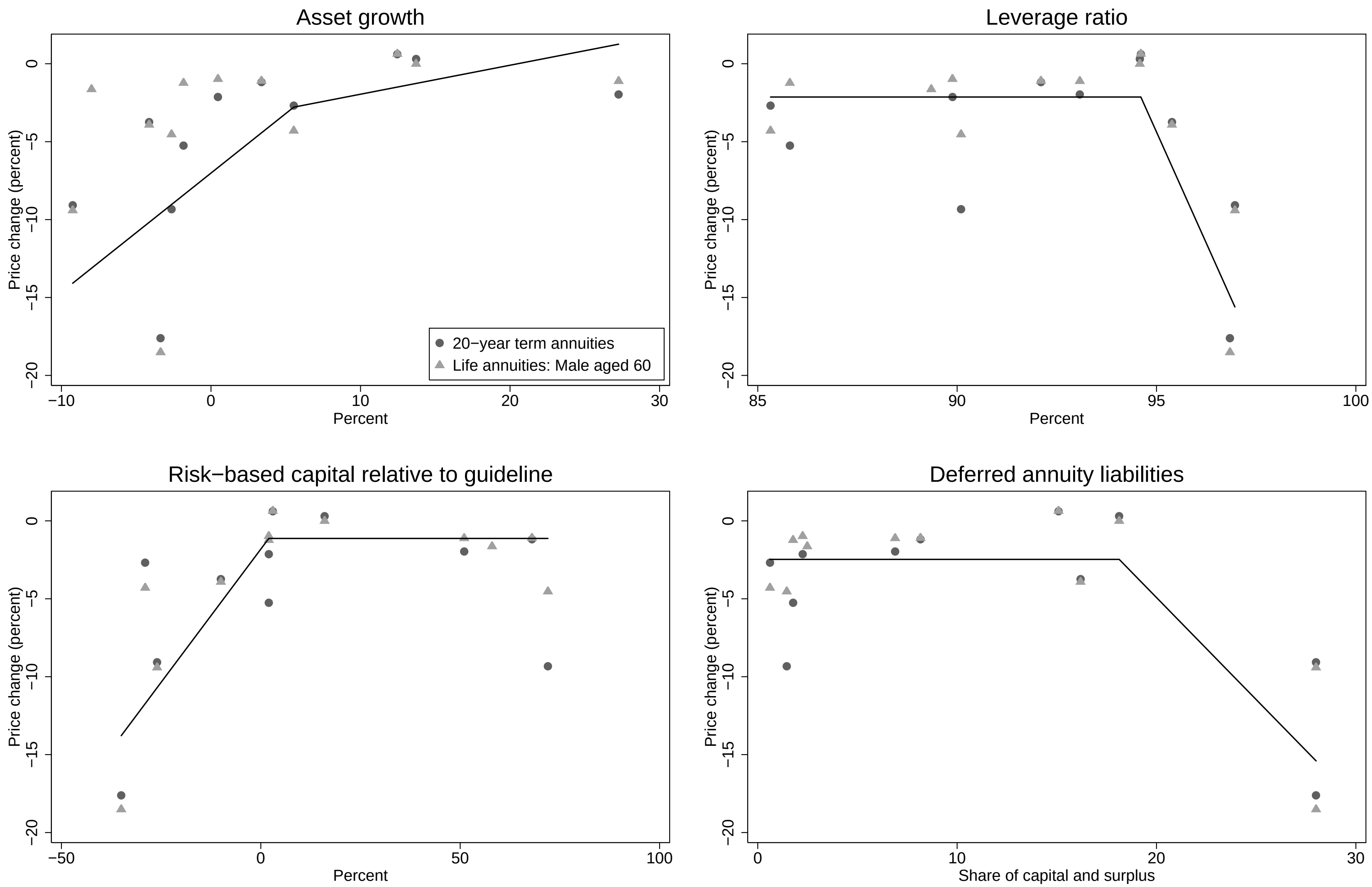

Figure 4: Price Change versus Balance Sheet Shocks in 2008

The percent change in annuity prices is from May 2007 to November 2008. The growth in total admitted assets is from fiscal year-end 2007 to 2008. The leverage ratio, risk-based capital (Best's Capital Adequacy Ratio) relative to guideline for the current rating, and the ratio of deferred annuity liabilities to capital and surplus are at fiscal year-end 2008. The monotone linear spline weights the observations by total admitted assets at fiscal year-end 2007.

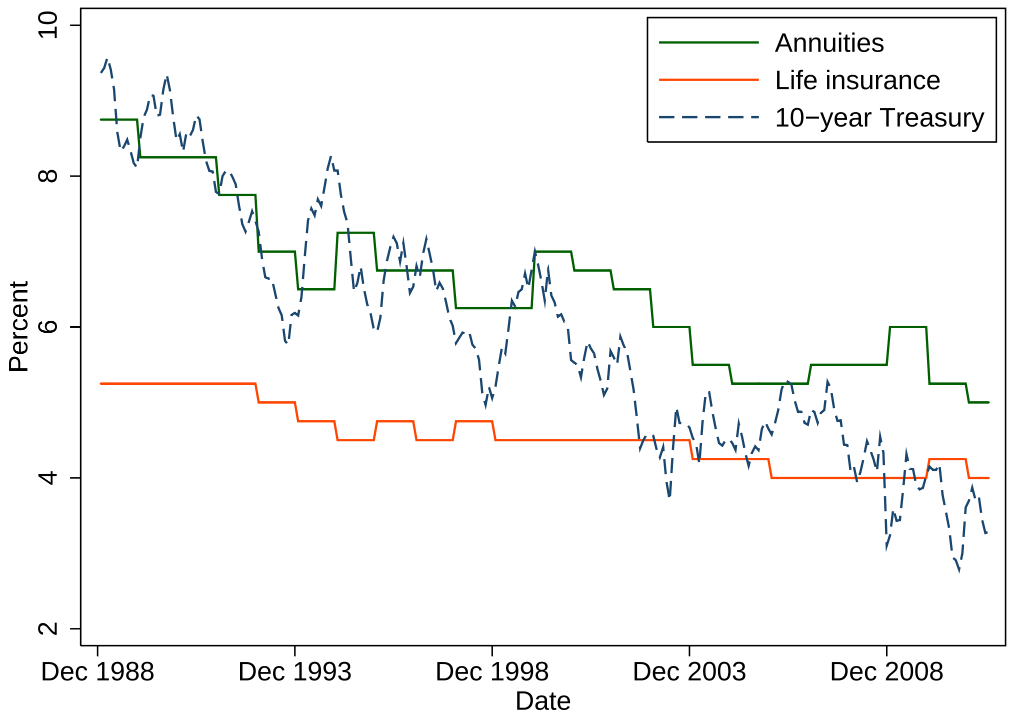

Figure 5: Discount Rates for Annuities and Life Insurance
This figure reports the discount rates used for statutory reserve valuation of annuities and life insurance, together with the 10-year zero-coupon Treasury yield. The monthly sample covers January 1989 to July 2011.

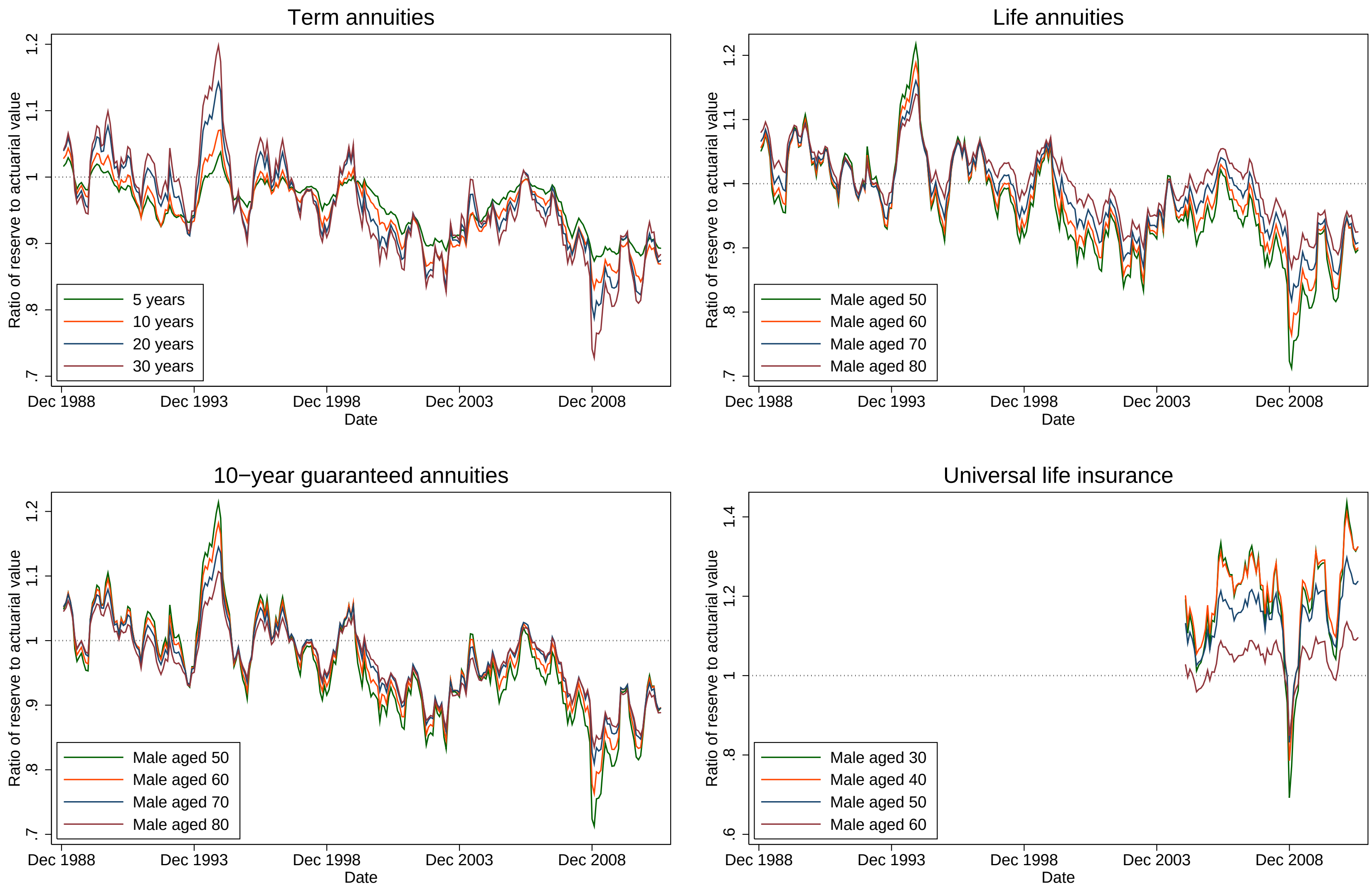

Figure 6: Reserve to Actuarial Value for Annuities and Life Insurance

The reserve value is based on the appropriate loaded mortality table from the American Society of Actuaries and the discount rate specified by Standard Valuation Law. The actuarial value is based on the appropriate basic mortality table from the American Society of Actuaries and the zero-coupon Treasury yield curve. The monthly sample covers January 1989 to July 2011 for annuities and January 2005 to July 2011 for life insurance.

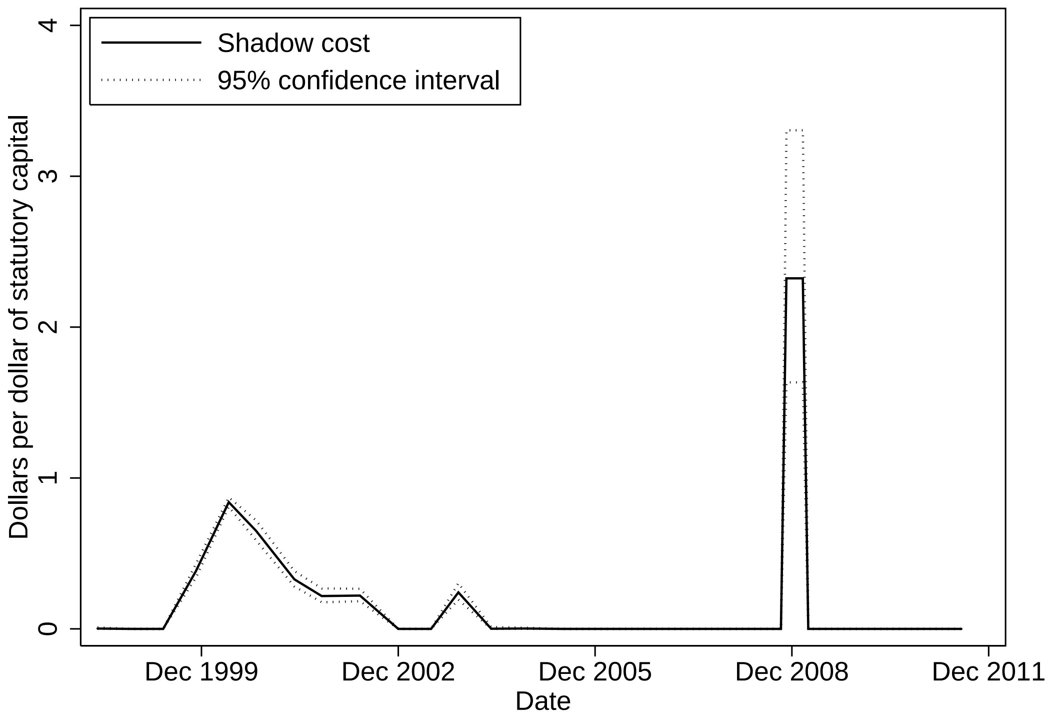

Figure 7: Shadow Cost of Financial Frictions

This figure reports the shadow cost of financial frictions, implied by the estimated model of insurance pricing, for the average insurance company. The 95 percent confidence interval is based on robust standard errors, clustered by insurance company, type of policy, sex, and age. The sample covers life insurers with an A.M. Best rating of A− or higher from May 1998 to July 2011.

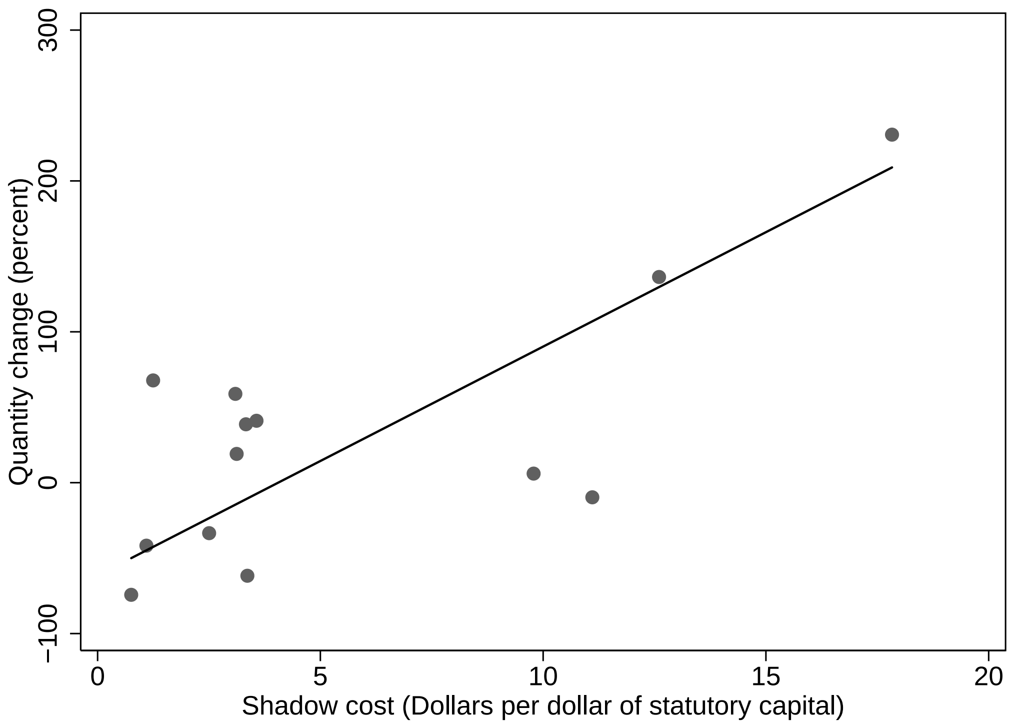

Figure 8: Change in Immediate Annuities Issued from 2007 to 2009
The percent change in the quantity of immediate annuities issued is from 2007 to 2009. The shadow cost of financial frictions in November 2008 is for the same set of insurance companies as in Table 4. The linear regression line weights the observations by total admitted assets at fiscal year-end 2007.

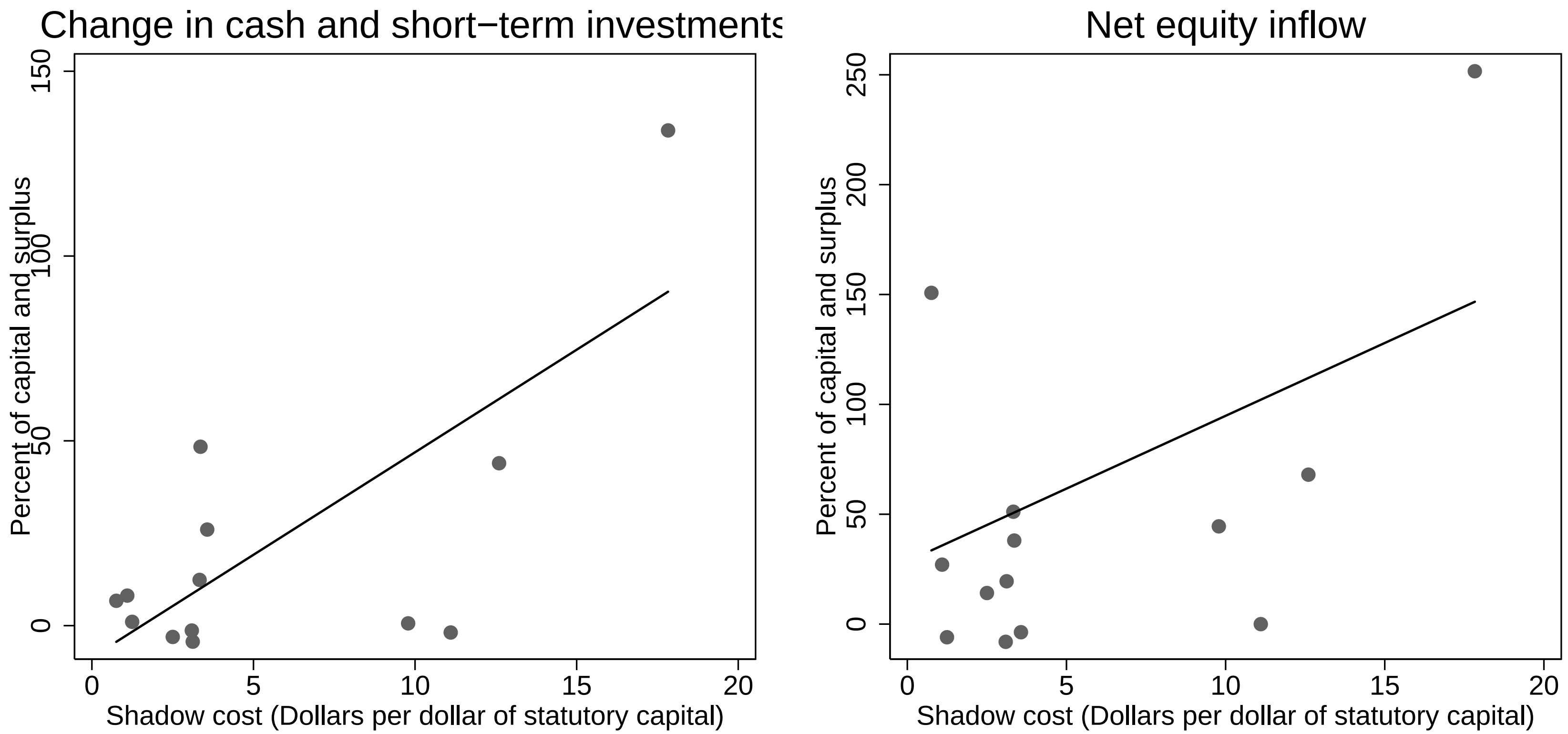

Figure 9: Conventional Channels of Recapitalization in 2008 and 2009

Net equity inflow (i.e., capital and surplus paid in minus stockholder dividends) and the change in cash and short-term investments in 2008 and 2009 are reported as a percentage of capital and surplus at fiscal year-end 2007. The shadow cost of financial frictions in November 2008 is for the same set of insurance companies as in Table 4. The linear regression line weights the observations by total admitted assets at fiscal year-end 2007.

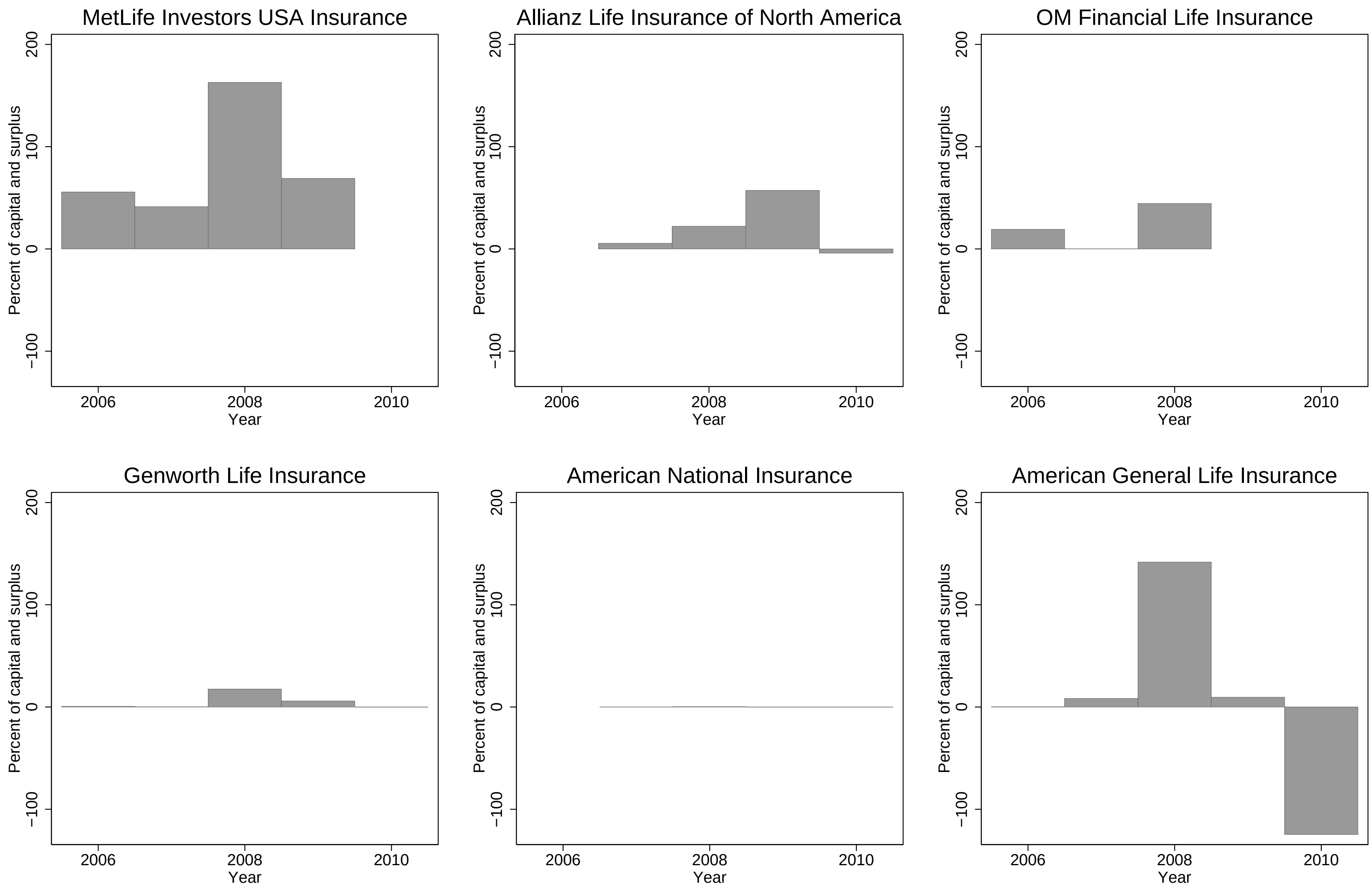

Figure 10: Equity Inflow from 2006 to 2010
The top (bottom) three panels are insurance companies with the highest (lowest) shadow cost of financial frictions in Table 4, among those with at least $10 billion in total admitted assets. Equity inflow (i.e., capital and surplus paid in) is reported as a percentage of capital and surplus at previous fiscal year-end.

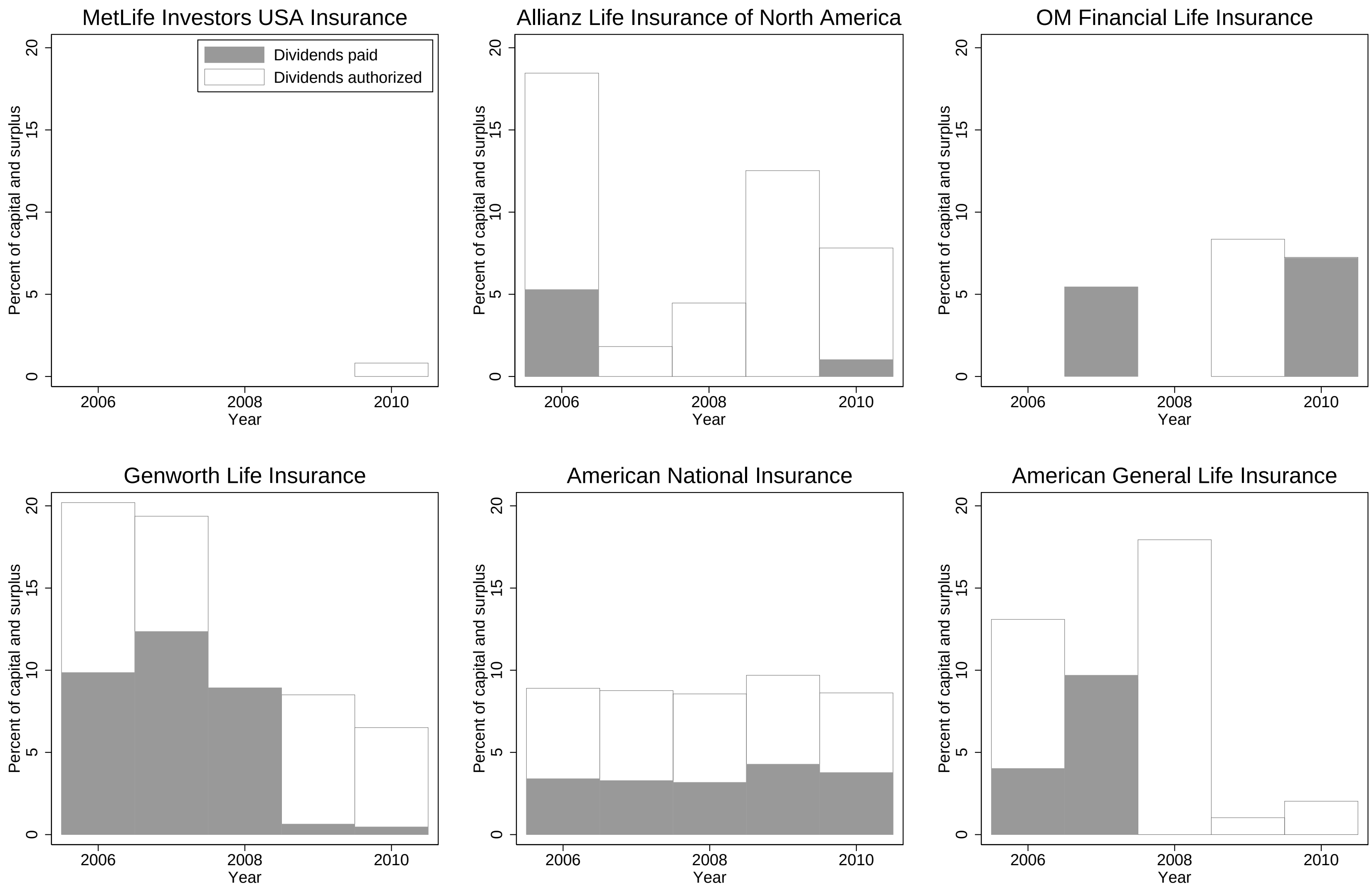

Figure 11: Dividends Paid versus Authorized from 2006 to 2010

The top (bottom) three panels are insurance companies with the highest (lowest) shadow cost of financial frictions in Table 4, among those with at least $10 billion in total admitted assets. Stockholder dividends and ordinary dividends authorized are reported as a percentage of capital and surplus at previous fiscal year-end. Ordinary dividends authorized is equal to the maximum of 10 percent of unassigned surplus funds and the net gain from operations for the previous fiscal year, calculated according to the Insurance Holding Company System Regulatory Act.