The hunt for duration: not waving but drowning?*

Dietrich Domanski
Bank for International Settlements
dietrich.domanski@bis.org

Hyun Song Shin
Bank for International Settlements
hyunsong.shin@bis.org

Vladyslav Sushko
Bank for International Settlements
vlad.sushko@bis.org

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Abstract

Long-term interest rates in Europe fell sharply in 2014 to historically low levels.This development is often attributed to yield-chasing in anticipation of quantitative easing by the European Central Bank. We examine how portfolio adjustments by long-term investors aimed at containing duration mismatches may have acted as an amplification mechanism in this process. Declining long-term interest rates tend to widen the negative duration gap between the assets and liabilities of insurers and pension funds, and any attempted rebalancing by increasing asset duration results in further downward pressure on interest rates. Evidence from the German insurance sector is consistent with such an amplification mechanism.

JEL classification: E43; G11; G12; G22
Keywords: *Long-term yield compression; insurance sector; liability-driven investment; duration mismatch.*

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1 Introduction

Long-term interest rates in Europe fell sharply in the second half of 2014. Between end-August 2014 and January 2015, 10-year government bond yields in France and Germany fell by more than 1 percentage point. In early 2015, French 10-year rates were below 0.25 percent and in April 2015 the corresponding German rates hovered close to zero. This decline in long-term interest rates came against a backdrop of easy funding conditions and firming expectations of large-scale asset purchases by the European Central Bank (ECB) (see BIS, 2015a). Notably, long-term interest rates declined due to the compression of term premia rather than to changes in expected future real rates (see Figure 1). This indicated unusually strong demand for long-term debt.

In this paper, we analyse the impact of asset–liability duration matching by insurance firms on long-term interest rates. While the optimal portfolios of long-term investors, such as insurance firms, differ significantly from short-term investors (Campbell and Viceira, 2002), little work exists analysing their investment behaviour from a financial stability perspective. Life insurers typically have long-term fixed obligations to policy holders and beneficiaries. In many cases, these liabilities have a longer maturity profile than that of the fixed income assets held to meet those obligations (EIOPA, 2014a,b), implying a negative duration gap that fluctuates with movements in long-term interest rates. Prudent management of interest rate risk influences the choice of the asset portfolio towards matching the sensitivity of assets and liabilities to further changes in long-term rates. Accounting rules and solvency regulations may reinforce the imperative to manage duration mismatches.

Duration-matching strategies of insurers and other long-term investors can amplify movements in long-term interest rates. When long-term rates fall, the duration of both assets and liabilities increases, but negative convexity implies that the duration gap becomes larger for any given portfolio of bonds. Closing the duration gap entails adding longer-dated bonds so that the duration of assets catches up with the higher duration of liabilities. If a sufficiently large segment of the market is engaged in such portfolio rebalancing, the market mechanism itself may generate a feedback loop whereby prices of longer-dated bonds are driven higher, serving to further lower long-term interest rates and eliciting yet additional purchases.[1]

[1] Another source of convexity, relevant for steeply rising rates and not discussed in this paper, arises from

The amplification effect of the dynamic hedging of duration mismatches has been analysed in other contexts. A well-known issue is convexity risk due to the prepayment option in US mortgage contracts. Because of this option, mortgage prepayments vary with the level of interest rates. Investors in US mortgagebacked securities (MBS) who attempt to hedge the resulting changes in duration gaps may end up amplifying movements in long-term rates [see, among others, Fernald, Keane, and Mosser (1994), Hanson (2014) and Malkhozov and other (2015)]. As in the case of the MBS prepayment option, a negative duration gap may encourage dynamic hedging of convexity risk, which in turn can create a feedback loop between investor hedging and market prices, amplifying movements in long-term interest rates.

Our paper's contribution comes in three parts. In the first part, we lay out key institutional features that govern the management of bond portfolios of European insurance firms and that may incentivise duration matching. In the second part, we sketch a simple example of a duration-matching investor and derive a closed-form demand function for long-dated bonds. Because of negative balance sheet convexity, the duration of liabilities rises faster than the duration of assets, and this gap widens nonlinearly with a fall in rates. Hence, for some ranges of longterm interest rates—especially for low or negative rates—an increase in the price of a bond elicits greater demand for that bond. In other words, the demand function slopes upwards.

The third part is empirical. We examine the maturity profile of government bond holdings of the insurance sector in Germany using data provided to us by the Deutsche Bundesbank, with a special attention on how the maturity of bond holdings adjusts to shifts in long-term interest rates. We find that the key predictions of the duration hedging hypothesis are borne out. We explore the extent to which the demand response of insurance firms was upward-sloping in recent years.

Our main findings can be summarised as follows:

First, for 2014 we document the largest portfolio reallocation towards government bonds

policyholders' surrender option. As interest rates rise, policyholders may choose to exercise their surrender option, which allows to them terminate their policies at predetermined surrender values. Yet, the declining values of insurers' bond holdings, amid rising rates, could render life insurer assets insufficient to cover the aggregate surrender values of policyholder claims, possibly causing a run. Feodoria and Foerstemann (2015) document that German life insurance companies have become less resilient to such a shock, with the associated critical interest rate level declining from 6.3 to 3.8 percent between 2007 and 2011.

by the insurance sector observed during the past 4 years. The nominal value of government bond holdings increased by 16 percent compared with an average of 6.9 percent for the preceding 3-year period.

Second, this portfolio reallocation was accompanied by a significant increase in the duration of government bond holdings, by almost 40 percent (from 11.3 to 15.7 years in 2014). At the same time, the duration of liabilities rose sharply in 2014, by an estimated 20 percent (from 20.5 to 25.2 years).

Third, the hunt for duration seems to have amplified the decline in euro area bond yields in 2014. We find that the demand response of German insurers to government bonds became upward-sloping in 2014. The relationship between bond prices and bond demand is nonlinear in bond duration, a result that is robust to alternative regression specifications. Statistical tests confirm that duration is the state variable that determines the sign of the price elasticity of bond demand by the insurance sector.

Fourth, the hunt for duration by the insurance sector appears to be distinct from the typical search for yield. We do not find a similar demand response for other sectors in Germany, including investment funds, banks and private households.

Fifth, although our data allow for only a tentative estimate of the impact of insurers' portfolio shifts on market yields, we find that the feedback effects from rising bond demand in an environment of falling yields may have been significant. In 2014, German insurers were responsible for about 40 percent of the net acquisition of bonds by German residents, even though insurers only account for 12.5 percent of the direct holdings of bonds by German residents. Furthermore, the higher duration of German government bond (bund) holdings by German insurers was associated with higher 3-month-ahead excess returns on holdings of bunds and lower future realised bund yields—analogous to the impact of convexity hedging by MBS investors on US Treasury yields.

Our findings puts the fall in the term premium in late 2014 and early 2015 in a different light from the usual interpretation that it was a sign of investor riskseeking. Rather than exuberance on the part of investors who are happy to take on more risk, it could have been, at least in part, the consequence of attempts of insurers to contain the financial risks represented by duration mismatches. The expression "not waving but drowning" in the title of our paper makes reference to the poem of the same title by the British poet Stevie Smith.[2] Her poem describes the flailing by a drowning man being mistaken by on-lookers as waving. In the same vein, the deeply negative term premium may have been associated with attempts to keep risks in check, not of exuberance that seeks greater risk. Ironically, such prudent risk management at the firm level may have had an aggregate effect of contributing to an undershooting of long-dated yields.

We see our work as contributing to the understanding of amplification mechanisms in the financial sector. While research in the aftermath of the financial crisis focused on procyclical behaviour of banks (see, e.g. Adrian and Shin, 2010), a growing body of literature is investigating such mechanisms in the non-bank financial sectors. Fund managers may behave procyclically because of performance benchmarking (Feroli et al, 2014; Morris and Shin, 2015) or when exposed to short-term redemptions of funds (Shek, Shim, and Shin, 2015). Our work can possibly provide building blocks for future work on ascertaining the extent to which amplification mechanisms in the insurance and pension fund sector contributed to the rapid decline in long-term rates in 2014 and in early 2015.

Our results also shed light on the transmission of central bank asset purchases in a financial system in which investors are subject to interest rate risk constraints. They relate to the discussion of investors' preferred habitat in the transmission of central bank policies implemented via bond purchases.[3] Our findings suggest that the institutional and regulatory structure of the financial system may matter for the significance of such preferred habitat behaviour. Duration-matching requirements due to investment mandates, internal risk limits or regulatory constraints make insurance companies and pension funds value certain types of security beyond their risk-adjusted payoff. Our results support the view that such differences matter for the risk exposures of financial institutions and the dynamics of longterm interest rates. They may also help explain the associated differences between the USA and the euro

[2] Stevie Smith, Not Waving but Drowning, see www.poetryfoundation.org/learning/poem/175778.

[3] See, for example, Bernanke (2013) on how imperfect substitutability provides a mechanism for quantitative easing policies by the central bank to affect asset prices. See also IMF (2015) for a discussion of the pension fund and insurance sectors' portfolio rebalancing in the context of central bank QE in Japan and the euro area. Chodorow-Reich (2014) finds a positive impact of monetary easing on equity values of life insurers in the US, suggesting that this was due to the positive impact on life insurers' legacy assets which were largely held in MBS. Joyce et al (2014) finds that portfolio rebalancing by UK insurance firms in response to Bank of England's purchases of Gilts was more pronounced for insurance firms less constrained by fixed rate liabilities (eg those with unit-linked products).

area (see also Koijen and Yogo, 2015).

Whether the hunt for duration is a more widespread phenomenon remains an issue for future research. Three observations suggest that this might be the case. First, investors with long-term liabilities—insurance companies and pension funds—are important investors in the euro area as a whole. At end-2014, they accounted for about 41 percent of the outstanding amount of euro area sovereign debt held by euro area residents. Second, insurers run negative duration gaps in a number of countries (see EIOPA, 2014a, b, Graph 78). And third, insurers in Europe are subject to comparable regulatory constraints, not least due to the forthcoming introduction of the Solvency II Directive in 2016.

Our paper starts by describing the significance of European insurance firms in bond markets, with a particular focus on the institutional and regulatory frameworks that govern their investment decisions. We then present a simple model of bond demand by institutions facing negative duration gaps and a solvency constraint. In the next step, we use data on the portfolio composition of German insurers to analyse the empirical relationship between bond yields, regulatory discount rates for insurers and their bond portfolios. We conclude by discussing implications of our findings for the assessment of quantitative easing (QE), including the relevance of the financial system's structure for the way QE works and the financial stability implications of duration matching by institutional investors.

2 Life insurers in the euro area bond market

Life insurance firms are the main providers of long-term saving contracts for retirement to private households in the euro area. By end-2014, according to ECB statistics, insurance companies held €6.8 trillion in assets, equivalent to almost 70 percent of euro area GDP. Pension funds, the other major provider of saving contracts for retirement, are much smaller in size, holding about €2.2 trillion in assets. This difference reflects the prevalence of pay-as-you-go public pension schemes, a generally limited role of corporate pensions, and a favourable tax treatment of life insurance contracts in a number of jurisdictions. That being said, life insurers and pension funds are often lumped together because of the similarity of products and business. In France, for example, pension products are offered by insurance companies, with the pension funds industry as such is almost non-existent.

The size of the life insurance sector as well as the design of life insurance contracts varies across major euro area countries. Assets managed by insurance firms range from 102 percent in France, 58 percent in Germany, 42 percent in Italy, to 26 percent in Spain. This compares with about 60 percent in Japan and 19 percent in the USA. Traditional term life contracts prevail in euro area countries. Contracts that offer guaranteed minimum returns constitute the bulk of outstanding contracts, while unit-linked contracts are gaining importance at the margin. German insurers, which are the focus of the empirical analysis in this paper, typically offer term life products with minimum return guarantees and minimum profit participation. The minimum return set at the inception of the contract cannot be changed during its lifetime (Berdin and Gru¨ndl, 2015). A higher share of guaranteed rate products tends to be associated with a long duration of liabilities and with a larger negative duration gap (IAIS, 2014).

Fixed income securities are the predominant asset class in the portfolios of euro area insurers. Of the €6.8 trillion mentioned above, about 45 percent (or €3.1 trillion) are direct holdings of securities other than shares. In addition, insurance firms hold another 22 (€1.2 trillion) in investment fund shares.[4] About half of the assets managed by such funds are made up of bonds (EFAMA, 2015). Taken together, direct and indirect holdings of fixed income instruments by euro area insurance firms amount to about 55 percent of their assets.

2.1 Features governing the asset-liability management of insurers

The investment strategies of life insurance firms are essentially liability-driven. Policyholders pay upfront premia, which life insurers invest in assets that match their long-term liabilities. The Committee on the Global Financial System (CGFS, 2011) describes two general approaches to such liability-driven investment strategies. One is partial immunisation through duration matching. This approach aims at mirroring the characteristics of liabilities by matching the interest rate sensitivities of assets and liabilities. The other approach is complete immunisation through cash flow matching. Here, investments aim at replicating the exact cash flow profile of liabilities.

[4]These are typically shares in funds owned by insurance firms, set up, in particular, because indirect investments through funds provide greater flexibility for portfolio management and, in some cases, tax advantages.

In addition to internal risk management policies, the sensitivity of life insurers' portfolio decisions to shifts in long-term interest rates depends on accounting standards and insurance regulation. In general, the likelihood of portfolio adjustments in response to changes in long-term interest rates increases with (1) the sensitivity of the valuation of assets and liabilities to changes in market conditions and (2) more binding risk limits. For instance, using market-based discount factors instead of fixed statutory discount rates will result in larger fluctuations of the value of liabilities. The firm could either accept these fluctuations (if internal or regulatory risk limits permit) or offset them with corresponding portfolio adjustments.

New accounting standards affect the valuation of insurance liabilities in ways that may increase incentives to pursue duration-matching strategies. Insurance contracts are currently accounted for under IFRS 4, Phase 1, which allows insurance companies to continue to use valuation methods as defined under national accounting standards. However, the next phase involves the introduction of a current measurement model for liabilities, determining the present value of expected cash flows. In response, insurers may opt for fair valuation of assets in order to reduce or eliminate accounting mismatches between assets and liabilities (CGFS, 2011). This, in turn, tends to make duration matching more attractive: it reduces balance sheet volatility in the face of interest rate shocks, which have an immediate, asymmetric effect on the fair value of asset and liabilities.

Changes in insurance regulation are working in the same direction as fair value-based accounting of liabilities. The forthcoming introduction of the Solvency II regulatory framework might already have made the portfolio decisions of insurance firms more sensitive to lower long-term interest rates. In particular, the present value of liabilities is calculated by estimating the present value of the expected net payments to policy holders and using a discount rate curve based on the euro swap rate curve.[5] Hence, shifts in the market term structure affect the value of liabilities much more immediately than under the current Solvency I regulatory framework (where liabilities are valued at book value).

When there is a negative duration gap, falling discount rates tend to put pressure on

[5] Market swap rates are used up to about 20-year maturities, or the last liquid point of the interest rate term structure. After this point, discount rates are extrapolated towards the so-called ultimate forward rate, an ultra-long rate based on broad assumptions about long-term growth and inflation (e.g. future real rates), see EIOPA (2015).

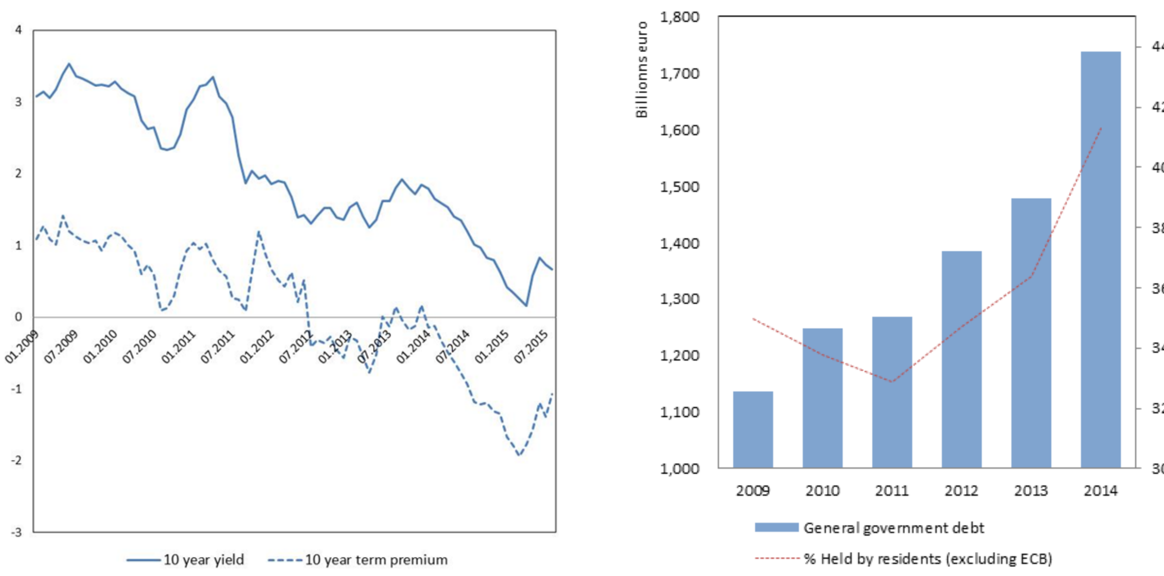

Figure 1: Long-term bond yields in the euro area and their term premium component (left) and holdings of general government bonds by euro area insurance companies and pension funds (right).

insurers' solvency ratios, because liabilities are more sensitive than assets to fluctuations in the discount curve. Moreover, because of the convexity property of conventional fixed income instruments, negative duration gaps tend to widen as interest rates decline. Both effects create incentives to take on more duration risk in portfolios. Risk-based capital requirements are another factor that may have affected the asset management decision of insurance companies. Solvency II classifies European government bonds in domestic currency as risk-free, creating an incentive for insurance firms to overweigh these in their portfolios. At the same time, Solvency II imposes capital surcharges on the holdings of corporate bonds. Corporate bonds with lower ratings command a particularly steep capital charge, similar to that of equities. In contrast, triple-A rated covered bonds are treated favourably under the new risk-based capital rules, which would encourage insurance sector investment in covered bonds relative to corporate bonds.

To what extent these mechanisms have added to stronger demand for longterm government bonds during 2014 is ultimately an empirical question. On the one hand, it is not obvious that the impact on reported liabilities was as large as the shift in market discount rate curves suggest. Solvency II becomes binding only at the beginning of 2016, and fairly long grandfathering periods for the regulatory treatment of liabilities apply. Moreover, to the extent that market discount curves are already used, some of the mark-to-market impact could have been dampened by upward volatility adjustments which can be made to the discount rate curve, subject to regulatory approval.[6] Similarly, the introduction of new accounting standards requiring current valuation has been delayed. While the introduction of IFRS 4 Phase 2 was originally planned for 2014–2015, the new relevant standard, now IFRS 17, is expected in early 2017, to become effective in 2020 or 2021. On the other hand, given the bond-like liabilities associated with the longterm obligations to policy holders and beneficiaries, prudent management of interest rate risk would imply that long-term investors pay strict attention to fluctuations in long-term rates and adjust their portfolios so as to manage interest rate risk. In this sense, the proposed regulations affecting the insurance sector may merely be reflecting the prudent risk management practices of the individual firms. Indeed, a survey of asset–liability management practices among 287 international insurers suggests that their awareness of balance sheet risks, and the focus on immunisation had increased worldwide and well before the accounting and regulatory changes discussed above (Smink and van der Meer, 1997).

2.2 Duration matching and bond market investment

Duration matching naturally favours instruments with relatively low credit risk and stable cash flows over long time horizons—typically long-term government bonds—over riskier corporate debt or equity investments. Indeed, insurance companies are among the largest investors in euro area government bond markets: by end-2014, they accounted for about 40 percent of the holdings of government debt by euro area residents (Figure 1, right-hand panel). However, despite their large holdings of bonds, in a number of euro area countries, the duration of insurers' liabilities exceeds that of their fixed income portfolios substantially. Austrian and German insurance firms run negative duration gaps of about 10 years, while Dutch, Finnish and French insurance firms run gaps of about 5 years (EIOPA, 2014a, b).

The sharp compression of term premia in euro area bond yields since mid-2014 may be

[6] Short-term solvency pressures arising from the asymmetric effects of low yields on mark-to-market values of assets and liabilities are distinct from long-term pressures on solvency that may arise if yields stay low for a prolonged time period; for the empirical analysis of the latter, see, for example, Kablau and Weiss (2014).

partly related to a further rapid increase in the bond holdings of euro area insurance firms and pension funds. The government bond holdings of such entities increased by an estimated €60 billion. In fact, several episodes of term premium compression of UK government bonds (gilts) have been empirically linked to demand shocks from pension funds and life insurers in the UK (Zinna, 2016). In addition to cash instruments, derivatives can also be used for duration matching.[7] Entering an interest rate swap as receiver of fixed rate payments allows investors to increase duration with no, or limited, upfront payment.[8] However, replicating the duration of a long-term bond (to reflect coupon and principal payments) requires taking relatively large swap positions. In addition to entering a swap right away, investors can use options to enter an interest rate swap at a future date (swaption) to hedge interest rate risks. Perli and Sack (2003) find that an increase in MBS prepayment risk, which would make convexity more negative or reduces duration, has been associated with a rise in the swaptionimplied volatility of long-term US dollar swap rates. They also show that the associated hedging activity tends to amplify movements in the 10-year swap rate. More recently, Klingler and Sundaresan (2016) find that duration hedging by defined benefit pension funds in the United States has served to drive 30-year swap rates lower.

Interest rate swap markets in the euro area are shallower, which may explain why increased demand for long-term swaps by Dutch pension funds almost brought the swap market down in 2008 (Geneva Association, 2010). When longterm interest rate fell sharply in December 2008, Dutch pension funds' coverage ratios fell to about 95 percent, and their attempts to close their interest rate gaps via the use of swaps were associated with a 31 percent cumulative decline in the 50-year swap rate in just two days (3–4 December).[9]

Figure 2 shows that in just 1 year between 2014 and 2015, the long end of the euro swap curve declined by over 150 basis points. The available, though incomplete, information at hand suggests that the use of derivatives by insurers has been limited. According to market sources, derivatives exposures account for between 2 and 4 percent of the total assets of large euro area insurance firms. Such derivatives would include not only interest rate

[7] Indeed, US investors exposed to negative convexity, such as MBS holders, have been largely relying on interest rate swaps rather than US Treasuries for dynamic hedging.

[8] Buying duration through swaps does, however, increase exposure to margin payments throughout the life of the swap contract.

[9] For the use of interest rate swaps by US life insurance firms, see, for example, Berends and others (2013).

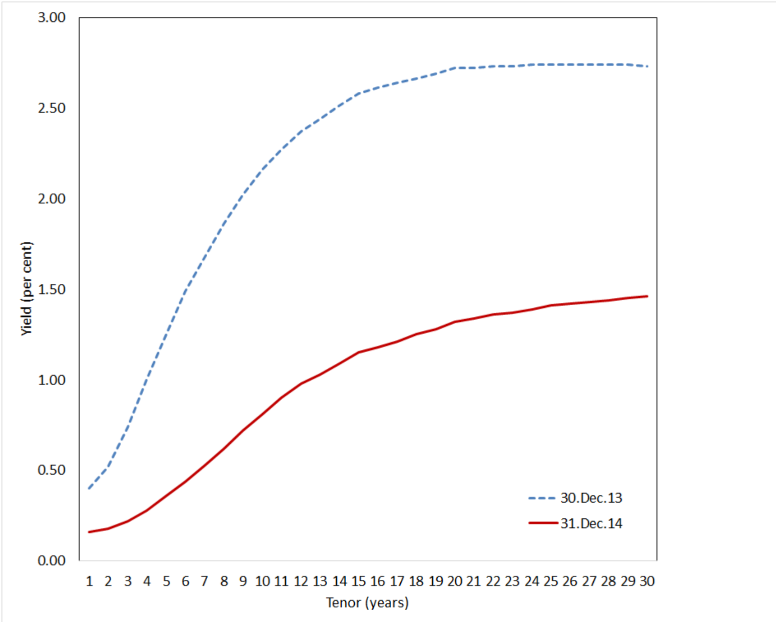

Figure 2: Euro swap curve, end-2013 compared to end-2014.

contracts but also credit default swaps (CDS). In a separate communication with the BIS, insurance firms have reported that derivatives, such as interest rate swaps, are useful for position-taking in the short run but that these firms tend to convert those positions into onbalance sheet exposures in the underlying cash assets over a longer decision horizon. In any case, an increase in duration achieved through the use of interest rate swaps would imply an economically equivalent market impact to buying bonds due to arbitrage between cash and derivatives markets.

3 Stylised example of duration matching

In this section, we present an illustration of how duration matching may lead to an upward-sloping demand curve for long-dated bonds. We build on an example given in Shin (2010) of a liability-driven investment strategy that attempts to hedge against interest rate risk. The example illustrates how the response of investor demand to a change in the price of a fixed income asset can be abnormal in the sense that an increase in the price elicits even greater demand.

When an institution has fixed payment liabilities and holds fixed income assets against them, the value of both assets and liabilities increases as the discount rate falls. For a given decline in the discount rate, the magnitude of this increase depends on the convexity of liabilities and assets. In particular, when the institution's balance sheet gives rise to negative convexity, the value of liabilities increases faster than the value of assets. If the institution wants to offset the relative decline in the value of its assets, it needs to increase its holding of fixed income assets when interest rates fall.[10] In other words, its demand for fixed income assets increases as the price increases. The demand curve is upward-sloping.

We use a simple model to derive the upward-sloping demand curve. Consider an insurance company whose asset portfolio consists of cash and a riskless T-period zero coupon bond with principal amount 1. Denote by M the firm's cash holding and by B the market value of the firm's holding of the benchmark bond. Total assets of the insurance company is denoted by A, so that

$$A = M + B \tag{1}$$

Let p denote the price of the benchmark bond, and denote by r its yield. Thus,

$$p = \frac{1}{(1+r)^T} \tag{2}$$

The duration of the benchmark bond is the proportional change in price in response to changes in its yield. Formally, the duration of the benchmark bond is given by

$$-\frac{dp/dr}{p} = \frac{T}{1+r} \tag{3}$$

The liabilities of the life insurance company are given by its annuity commitments sold to policy holders. We assume that the individual policy holders are small, so that the aggregate cash flow commitment follows a deterministic payment schedule in accordance with the actuarially fair value of payments to individual policy holders. The firm's aggregate cash flow commitment is assumed to be:

$$C, \quad (1+g)\,C, \quad (1+g)^2\,C, \cdots \tag{4}$$

[10] In principle, the institution could also increase asset duration through interest rate swaps. Economically, this is equivalent to buying bonds, and the cash market can be expected to react as if bonds were purchased through arbitrage.

where $g < 0$ is a decay parameter such that $-1 < g < 0$.

The insurance company values its liabilities by discounting the payments to policy holders using the yield r on the benchmark T-period bond.

The value of the insurance liabilities is:

$$L = \frac{C}{1+r} + \frac{C(1+g)}{(1+r)^2} + \frac{C(1+g)^2}{(1+r)^3} + \cdots \tag{5}$$

Multiplying through by $\frac{1+r}{1+g}$ gives

$$\frac{1+r}{1+g} L = \frac{C}{1+g} + \frac{C}{1+r} + \frac{C(1+g)}{(1+r)^2} + \cdots \tag{6}$$

Subtracting (6) from (5) and re-arranging,

$$L = \frac{C}{r-g} \tag{7}$$

The balance sheet identity of the insurance company can be written as

$$M + B = L + E \tag{8}$$

where E is the equity of the insurance company, defined as the residual value of assets net of liabilities.

Denote by y the number of units of the benchmark bond held by the insurance company, so that the $B = py$. The insurance company adjusts y so as to immunise its balance sheet to changes in r. In other words, it adjusts its holding y of benchmark bonds to ensure that its equity E is locally insensitive to changes in the yield r. The duration of the company's liabilities is the proportional change in the value of L to changes in the discount rate r. It is given by

$$\begin{aligned} -\frac{dL/dr}{L} &= \frac{C/(r-g)^2}{C/(r-g)} \\ &= \frac{1}{r-g} \end{aligned} \tag{9}$$

For immunisation of the company's equity value, the holding y of the benchmark bond

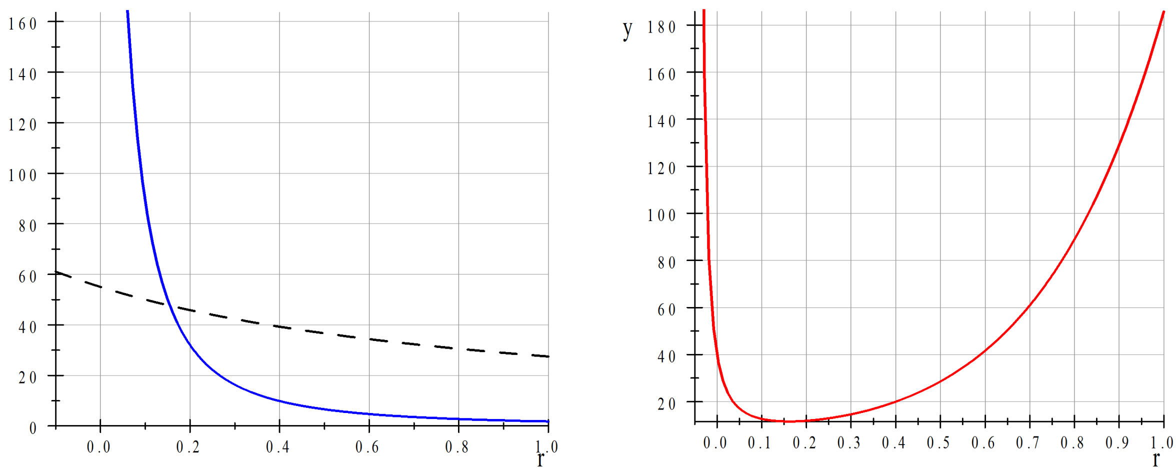

Figure 3: Convexity of assets (dashed) and liabilities (solid), keeping holdings of benchmark bond fixed (left) and holding of benchmark bond in the immunising portflio (right); for T=10, C=0.5, and g=-0.05.

must satisfy:

$$\begin{aligned} py \times \frac{T}{1+r} &= L \times \frac{1}{r-g} \\ y \times \frac{1}{(1+r)^T} \times \frac{T}{1+r} &= \frac{C}{r-g} \times \frac{1}{r-g} \end{aligned} \tag{10}$$

The left hand side of (10) gives the rate of change of the asset side of the balance sheet to small changes in the discount rate r. It is the product of the duration of assets and the market value of total assets. The right hand side of (10) is the rate of change of the liabilities side of the balance sheet to small changes in the discount rate r, given by the product of the duration of its liabilities and the market value of its liabilities.

By imposing condition (10), we stipulate that the insurance company immunises itself from fluctuations in its equity that results from shifts in the discount rate r. Solving for y, we have:

$$y = \frac{C\,(r+1)^{T+1}}{T\,(g-r)^2} \tag{11}$$

Figure 3, left-hand panel, plots convexity of assets and liabilities if the holdings of the benchmark bond had been constant, while Figure 3,right-hand panel, plots the holding of the benchmark bond in the immunising portfolio; both scenarios are for the case of $T = 10$ and $C = 0.5$.

The numerical plots show that the holding of the benchmark bond is a non-monotonic function of the discount rate r. When the yield of the benchmark bond is low enough, the portfolio holding of the bond is *decreasing* in its yield. In other words, the demand curve for the bond is perverse in that a higher price of the bond elicits greater demand for the bond.

The reason for the perverse demand response is that, when liability convexity exceeds asset convexity, the duration gap widens at an increasing rate. This means that the value of liabilities rises faster than the value of assets as the discount rate falls below a given threshold level. In order to immunise the balance sheet against further shifts in r, the firm needs to increase its holding of the benchmark bond when the yield falls.

The expression for the holdings of the benchmark bond y given by (11) holds as long as the insurance company has sufficient funds to purchase the bonds required to match duration. We thus need to complete the solution by imposing a solvency constraint on the insurance company. Solvency requires $E \geq 0$. From the balance sheet identity, solvency implies $M + B \geq L$. If the cash holding has been exhausted, solvency reduces to $B/L \geq 1$.

Meanwhile, from our solution, the total value of bond holding is given by

$$B = py = \frac{C(1+r)}{T(g-r)^2} \tag{12}$$

The marked-to-market value of liabilities is

$$L = \frac{C}{r-g} \tag{13}$$

Hence, the condition $B/L \geq 1$ is equivalent to

$$r \geq \frac{Tg-1}{T+1} \tag{14}$$

The lower bound on r given by (14) is a solvency constraint for the duration-matching insurance company. If the discount rate falls below this level, the immunisation strategy given by (11) is no longer consistent with the solvency of the insurance company.

It is worth noting that the solvency constraint could be relaxed (somewhat) by the use of derivatives. This is because derivatives, such as interest rate swaps, can add duration and because their notional value usually exceeds substantially the margin put up by the insurance company. In effect, derivatives allow the insurance firm to use leverage to magnify its duration position. The mark-to-market value of derivatives would be much lower than that of bonds, and hence would help alleviate the solvency constraint. However, since we do not have data on insurance company positioning in interest rate swaps, we abstract from this feature in the model. In any case, insurance firms' use of derivatives will be limited by the applicable regulations as by well as by prudent liquidity management by the firms themselves.

There are two broad implications from our algebraic example. First, the demand curve for fixed income securities can become perverse and slope upward if portfolio composition is influenced by immunisation incentives. Second, when yields become low enough, insurance companies cannot simultaneously immunise their portfolios and remain solvent. Either they must abandon immunisation or they become insolvent, or both.

We do not model the market equilibrium where duration-chasing investors are one part. The quantitative significance of perverse demand reactions clearly depends on the relative weight of duration-chasers in the market as a whole. We focus instead on the empirical task of mapping out the demand shifts of German insurance companies using the portfolio data supplied to us by the DBB.

4 Evidence from German insurance sector bond holdings

4.1 Data and variable construction

We use data on the aggregate bond holdings of the German insurance sector ("the insurance sector"). The data are based on DBB's securities holdings statistics. Under the collection guidelines of those statistics, financial institutions domiciled in Germany report any securities which they hold for domestic or foreign customers. The Bundesbank aggregated the data for our purposes.

The data provide a breakdown of bond holdings by issuer sectors: German government, governments of other euro area countries, governments of non-euro area OECD countries (advanced economies), governments of non-euro area non-OECD countries (EMEs), non-financial corporations, banks and other issuers. For each issuer category, a breakdown by maturity bucket is available as follows: less than one year, one to two years, two to five years, five to 10 years, 10 to 20 years, 20 to 30 years and more than 30 years. Finally, a breakdown into nominal and market values allows us to distinguish between valuation changes and net purchases/sales of bonds. The data cover year-end holdings until 2014.

The time series for nominal and market values of bond holdings for each bond class and maturity allow us to construct variables such as yield to maturity and duration. Let $y_t^{i,T}$ denote the year t quantity of bonds of maturity T issued by sector i. Let $p_t^{i,T}$ denote the price assuming these are zero coupon bonds. Taking a bond's par value as the numeraire, the nominal value of the corresponding bond holdings is just $y_t^{i,T}$ and market value is given by $py_t^{i,T}$. These two variables represent the two quantities observed in our dataset for each issuer sector, maturity, and reporting year.

Using these quantities, we are able to calculate the percentage change in bond price as:

$$\Delta p_t^{i,T} = \frac{py_t^{i,T}}{py_{t-1}^{i,T}} \times \frac{y_{t-1}^{i,T}}{y_t^{i,T}} - 1 \equiv \frac{p_t^{i,T}}{p_{t-1}^{i,T}} - 1. \tag{15}$$

Similarly, the yield-to-maturity implied by the data can be calculated as:

$$r_t^{i,T} = \left(\frac{y_t^{i,T}}{py_t^{i,T}} \right)^{1/T} - 1. \tag{16}$$

Hence, the sensitivity of a bond's price to a change in yield, the McCauley duration, follows as:

$$D_t^{i,T} = -\Delta p_t^{i,T} \times \frac{1 + r_t^{i,T}}{r_t^{i,T} - r_{t-1}^{i,T}}, \tag{17}$$

where Δ denotes the percentage change operator. Under the assumption that the portfolio consist of zero-coupon bonds, an alternative estimate of bond duration is given by $D_{ZERO,t}^{i,T} = T/(1 + r_t^{i,T})$.[11] Finally, the aggregate duration of bond holdings of each issuing

[11] When interest rate term structure is variable, an alternative measure is the Fisher–Weil duration, which is a generalisation of the Macaulay duration that computes the present values of the coupon payments using a

sector or of the entire bond portfolio can be approximated using the market value weighted averages of $D_t^{i,T}$ and $D_{ZERO,t}^{i,T}$. For each issuing sector i, the McCauley duration of the corresponding bond portfolio is thus: $D_t^i = \sum_T (py_t^{i,T} \times D_t^{i,T}) / \sum_m py_t^{i,T}$; and for the aggregate bond portfolio we have: $D_t = \sum_i py_t^i D_t^i / \sum_i py_t^i$.

Measuring the duration gap also requires a proxy for the duration of liabilities. We estimate the latter by using a growing perpetuity assumption, discounting through euro swap rates and benchmarking the 2013 value off the EIOPA stress test figure for Germany. Specifically, $D_{L,t} \equiv 1/(r_t^{T=25} - g)$, where $r_t^{T=25}$is the year t 25-year zero-coupon euro swap rate and $g < 0$ is assumed to be constant.[12]

We calibrate g by setting $D_{L,t=2013} = 20.5$, the number reported by EIOPA (2014b). Figure 5, left-hand panel, shows side-by-side the evolution of the duration of the aggregate bond portfolio of the insurance sector, D_t and $D_{ZERO,t}$ and the evolution of the duration of aggregate German insurance sector liabilities, $D_{L,t}$.[13]

4.2 Trends in bond holdings and duration

Figure 4 shows the evolution of the nominal value of bond portfolios of the insurance sector during the sample period. The year 2014 stands out because of the large increase of insurance sector investments in advanced economy government debt, which rose by more than one-third: from less than 60 to almost 80 billion euros between December 2013 and December 2014. This contrasts with the rise in bond holdings in 2012, which was primarily attributable to purchases of corporate bonds.

non-flat term structure. Since we do not have individual bond data or information on their coupon payment structure, such as measure is beyond the scope of this paper.

[12] We take the 25-year zero-coupon swap rate because this is the longest approximate maturity for which the euro swap market is still considered liquid. Above the approximately 20–25 year range, EIOPA extrapolates forward rates using the ultimate forward rate assumptions based on long-term expectations of broad macroeconomic fundamentals; see EIOPA (2015).

[13] While our estimates of the insurance sector liability duration are calibrated to match the 2013 number reported in EIOPA (2014a, b), the Bundesbank (2016) has published an alternative estimate of the mean duration gap of 6.0(compared to 10.7 published by EIOPA) in the German insurance sector, by taking smaller insures into account and using a different methodology.

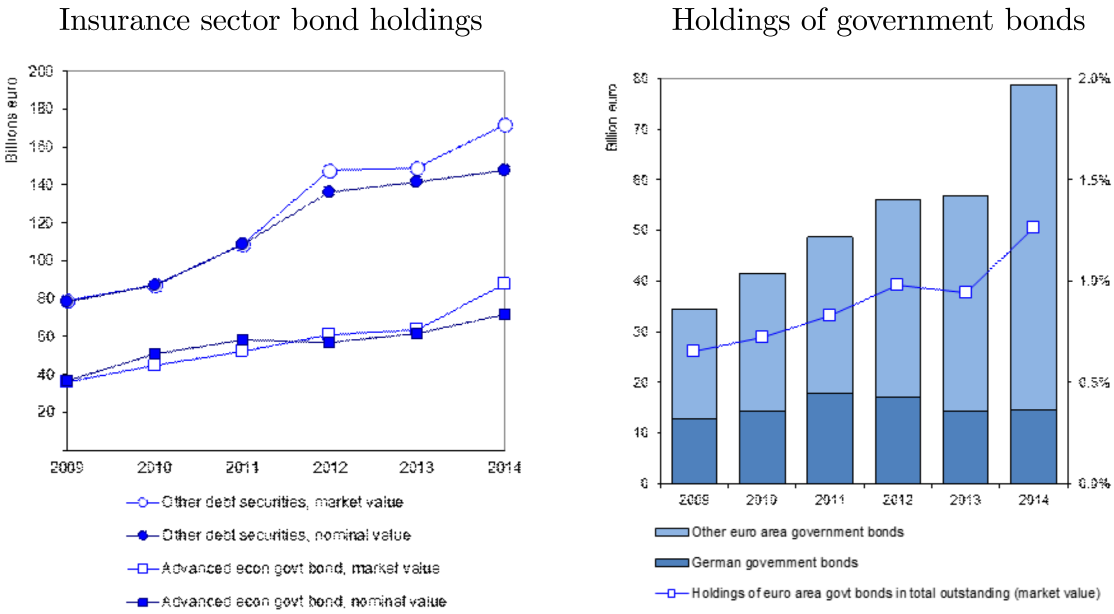

Figure 4: German insurance sector bond holdings: all issuing sectors (left) and euro area government debt relative to total portfolio and amounts outstanding (right).

Asset duration increased in lockstep with liability duration in 2014. In this single year, our estimated liabilities duration rose from 20.5 to 25.2 in just one year, as shown in Figure 5, right-hand panel. In other words, the lengthening of asset duration prevented the duration gap from widening. Figure 5 right-hand panel, shows that the increase in aggregate bond holdings of the insurance sector was associated with shift towards bonds with longer duration. The maturities above five years all show an increase in nominal value of bonds held in these buckets in 2014 compared to 2013. As the figure shows, most of the increase in bond portfolio duration is due to holdings of bonds with 10-20 and 20-30 year maturities.

The shift into bonds with longer maturities limited the amount of bonds insurers had to purchase to keep the duration gap in check. Our stylised model allows us to estimate the increase in bond holdings that would have been necessary to achieve the same duration gap with an unchanged bond duration of 12 years:

$$\Delta y_t = \Delta \left(\frac{D_{L,t}}{D_t} \times \frac{L_t}{p_t} \right). \tag{18}$$

The only new quantity in Equation (18) is insurance liabilities, eg technical reserves, L_t.

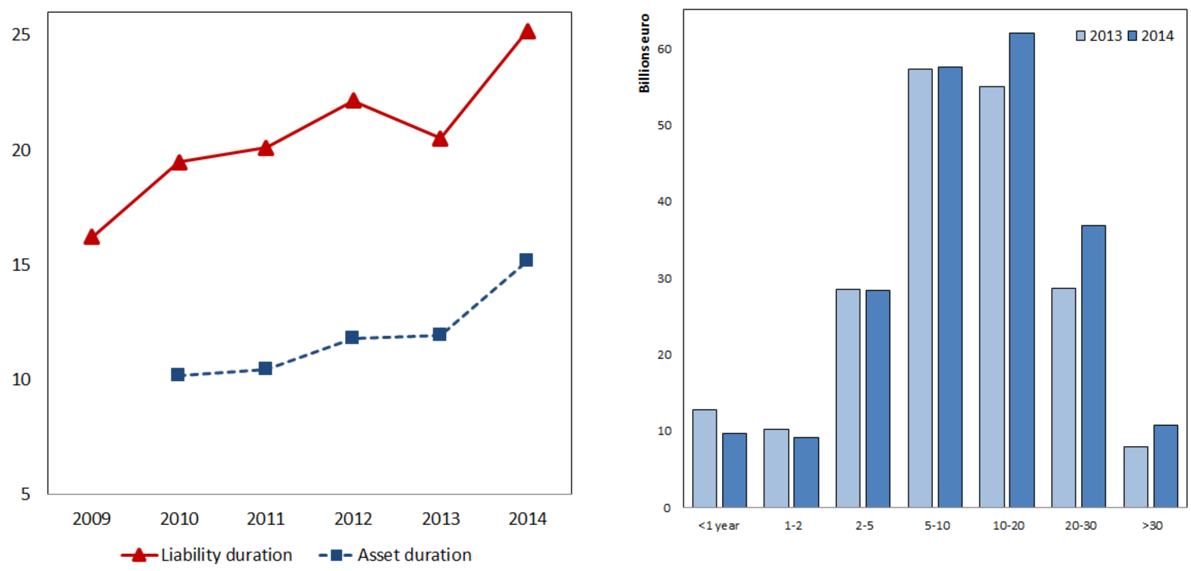

Figure 5: Trends in duration mistmatch (left); and maturity extension of bond portfoilio between from 2013 to 2014, nominal values (right). Notes: Duration of liabilities calculated assuming a growing perpetuity discounted using euro swap rates, with 2013 value benchmarked off of EIOPA stress test figure for Germany; duration of bond holdings calculated assuming zero-coupon bonds; the resulting duration gap does not account any offsetting effects from the use of swaps and derivatives.

According the DBB's public data, these increased by $\Delta L_t = 5\%$ from 2013 to 2014.[14]

The weighted average change in the price of bonds on insurers portfolio, in turn, was $\Delta p_t = 12.6\%$. By Equation (18), German insurance companies would have had to increase the nominal value of their fixed income securities holdings by 10.3%. The actual increase observed in the data was approximately 7.9%, or €15 billion, relative to the nominal value of bond holdings in the previous year. It was accompanied by a rise in the McCauley duration of the aggregate bond portfolio from 11.3 to 15.7 (Figure 5, left-hand panel).

In order to gauge the plausibility of such an increase in duration of bond holdings of German insurance sector, we compare our measure of duration and duration mismatch to a measure of interest rate sensitivity of German insurance sector derived from equity prices. To this end, we adopt the methodology of Hartley, Paulson, and Rosen (2016), who propose a measure of insurance firms' sensitivity to interest rate risk derived from the returns of their

[14] See item: Liabilities / Insurance corporations (ICs) / Insurance technical reserves / World / Total economy including non-residents (all sectors) / Outstanding amounts at the end of the period (stocks); available via http://www.bundesbank.de/Navigation/EN/Statistics/Banks_and_other_financial_institutions/Insurance_corporations_and_pension_funds/Tables/table.html

stock prices. Unlike these authors, we do not possess firm-level data; therefore, we work with German life insurance index data.

We estimate the following time-series model using weekly (Friday, end of week) data:

$$R_{Ins,t} = \alpha + \beta R_{m.t} + \gamma R_{10,t} + \varepsilon_t. \tag{19}$$

where $R_{Ins,t}$ is the weekly log return to the German life insurance sector index,[15] $R_{m.t}$ is the weekly log return to the German stock market index (DAX) and $R_{10,t}$ is the weekly change in the yield on German 10-year government bond. We estimate a rolling regression using a 2-year rolling window. Our interest is in the coefficient γ, which proxies for how news about changes in long-term interest rates are reflected into the stock prices of German life insurance firms. Following Hartley, Paulson, and Rosen (2016), we interpret nonzero estimates of γ as investor pricing-in some interest rate sensitivity in the insurance firms' profits.

Figure 6 shows the rolling regression coefficient γ, along with 90 percent confidence interval, as well as our annual estimates of the insurance sector bond holdings duration and the duration gap (computed as the difference between the two lines shown in Figure 5). Indeed, the rise in the estimated asset duration from approximately 12–15 between 2013 and 2014 has been associated with a significant rise in the life insurance sector equity returns sensitivity to changes in long-term yields. The estimate of $\gamma = 7.01$ at the end of the sample period indicates that a 10-bp point fall in 10-year bund yields would have been associated with a 0.7 percent fall in life insurers' equity prices.[16]

The portfolio reallocation observed in 2014 is consistent with a search for duration, rather than yield-seeking behaviour. The latter would predict a shift towards higher yielding, riskier assets, while search for duration would predict a shift toward longer maturity, safe assets, even at low yields. The dominance of the latter is corroborated by the disproportionate rise

[15] We use the index computed by Thomson Reuters DataStream, mnemonic LFINSBD.

[16] Bundesbank (2015) also reports that the rise in the maturity of life insurance companies' assets has worked to alleviate the duration mismatch, reducing the sector's vulnerability to longterm capital market risk. At the same time, it has made the insurance companies more sensitive to a sharp rise in interest rates. In addition, falling net return on investment was found to threaten the capital adequacy from one in 83 firms in the mild scenario to up to one in every four firms in the most severe scenario, by 2015.

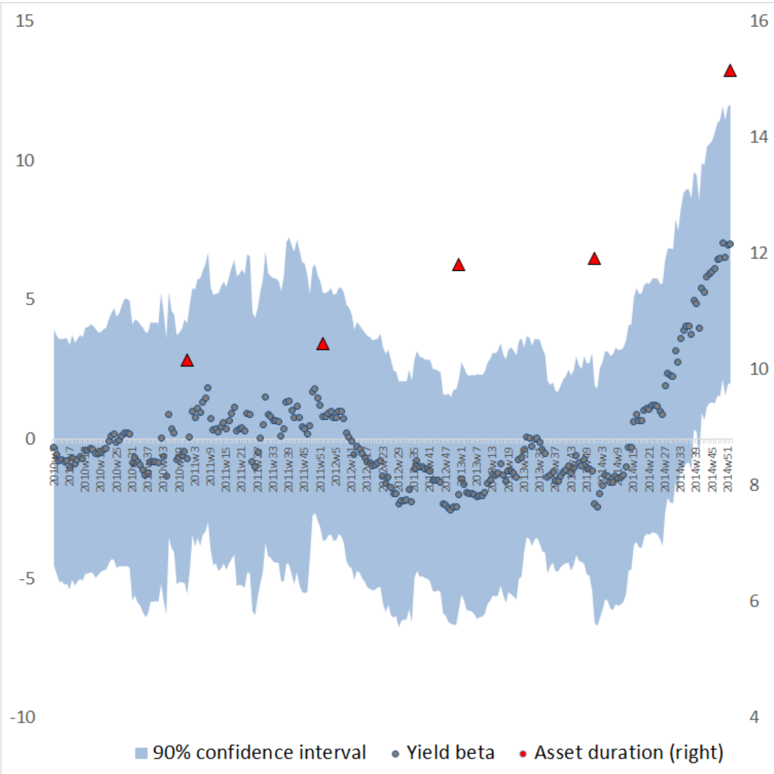

Figure 6: Interest rate sensitivity of German life insurance firms equity returns and the estimated duration of their fixed income assets.

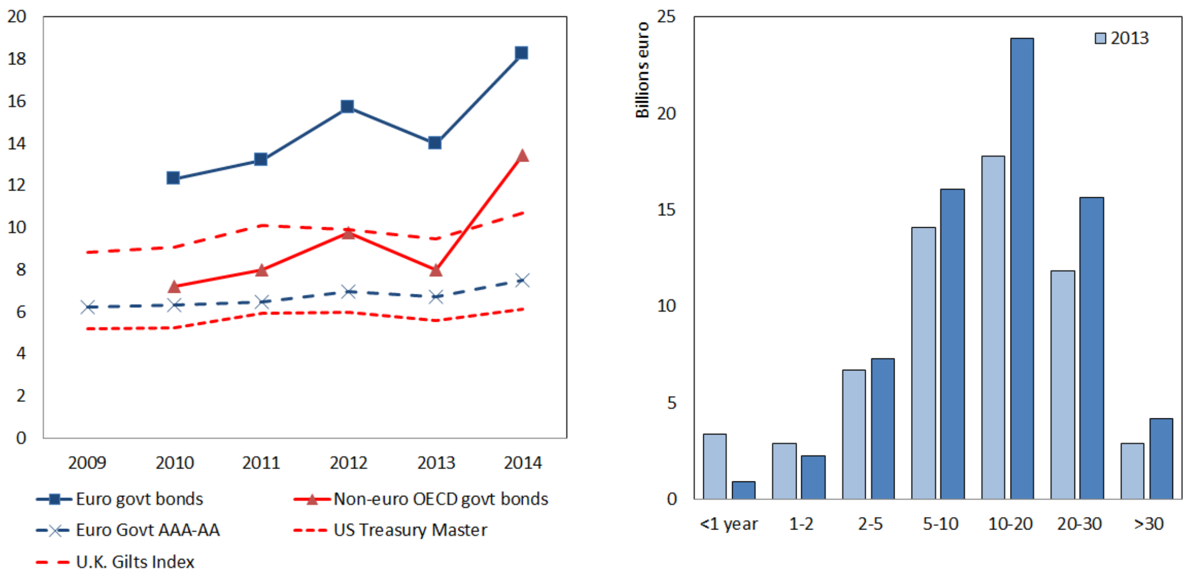

Figure 7: Duration of holdings of bonds issued by eurozone and other OECD governments, plus durations of corresponding benchmark BoA ML indices (left); and maturity extension of OECD government bond portfoilio from 2013 to 2014, nominal values (right).

in the duration specifically in the holdings of bonds issued by Eurozone and other OECD governments, shown in Figure 7. The left hand panel shows estimates of D_t^i for $i =$ eurozone government, other OECD governments. For comparison, we also plot the index durations of Bank of America Merrill Lynch (BoAML) Euro Govt AAA-AA Index, US Treasury Master Index, and UK Gilts Index. We chose the latter two for benchmarking non-Eurozone OECD government bond durations, because according company financial statements, German insurer investments in OECD government bonds outside of the Eurozone are almost exclusively in US Treasuries and UK Gilts, with approximately 8:2 split in favour of Treasuries.

4.3 Comparison with other major bond investors

Comparing the evolution of fixed income portfolio duration for other sectors provides a cross-check for the duration hunt hypothesis. The resulting liabilitydrivennature of portfolio management decisions should make the hunt forduration a unique feature of insurance firms. Other sectors with large bond holdings—private households, banks and investment funds—are in a different situation. Banks generally run positive duration gaps in line with their business model in which they borrow short and lend long. For private households, life insurance payments are typically used to finance consumption during retirement and can be interpreted as holding insurance contracts to match the duration of their consumption needs. Even for younger households who have taken on debt, they would not typically engage in active hedging of their liabilities.

A comparison between insurance firms and investment funds illustrates the differences between liability- and asset-driven portfolio management. Asset managers are constrained by performance relative to their peers and by redemption risks. Hence, they are more likely to behave like risk-averse mean variance investors, with any maturity extension of bond holdings in the low-yield environment driven by search for yield considerations rather than a duration target. To the extent that investment fund managers are also sensitive to relative performance considerations and deviation from industry benchmarks, the aggregate duration of their bond portfolios is likely to track the duration of benchmark indices much more closely that the duration of bonds held by insurance firms. Indeed, Opazo Raddatz, and Schmukler (2015) find that the maturity of mutual fund assets tends to be much shorter than that of insurance company assets, because the former are subject to short-run monitoring and hence are averse to holding more volatile and interest rate sensitive long-term assets. For these reasons, the institutional frictions that impinge on asset managers are likely to be of a different nature from those that affect insurance companies; asset managers are less subject to the imperative to match duration compared to insurance companies.

Figure 8, left-hand panel,shows that while the duration of bond portfolios of investment funds has gradually increased (from 8.3 to 9.9 between 2013 and 2014), it still falls within the range of the duration of benchmark indices (see Figure 7.). This is in sharp contrast duration of insurance companies' bond holdings, which has been persistently higher by 2–4 years, and has diverged further from that of investment funds, rising from 11.9 to 15.3 between 2013 and 2014. At the same time, the duration of the bond portfolios of banks and private households has changed relatively little.

This comparison supports the hypothesis that duration hunt is associated with negative duration gaps of insurance sector and not a general feature of asset management industry, even in the low rate environment. Figure 8, right-hand panel, shows that insurance companies have also increased their share of bond holdings relative to other major investor sectors, particularly holdings of OECD government bonds.

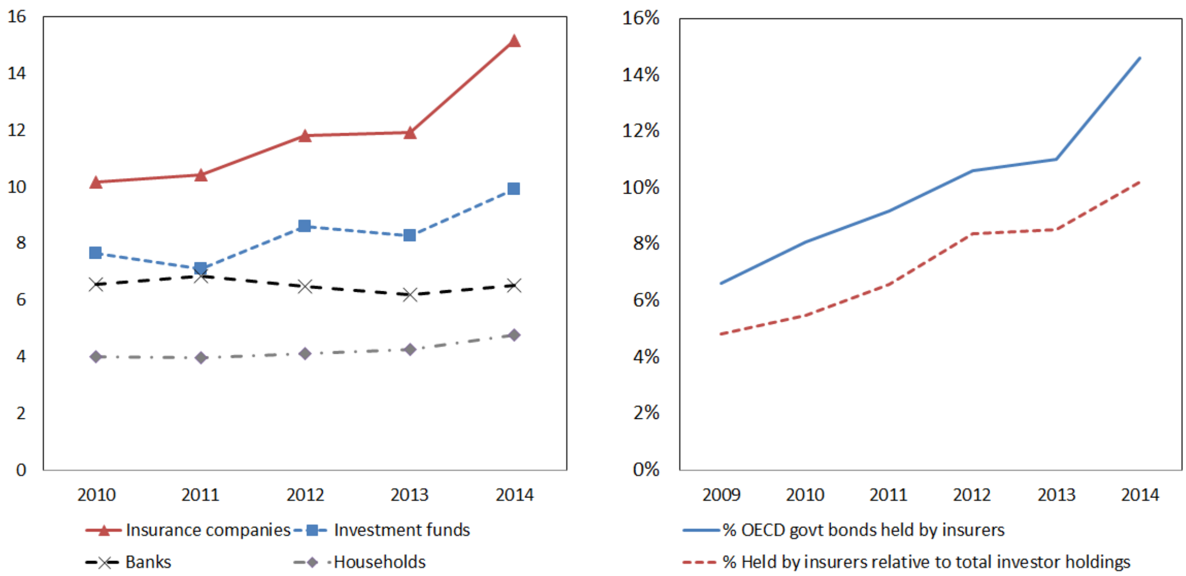

Figure 8: Comparison of bond portoflio duration between insurance companies and other major investor sectors; and trends in OECD government bond holdings relative to other major investor sectors. Based on bond portfolio allocation data of German insurance companies, investment funds, banks, and households

Figure 9 compares the changes in the maturity distribution of OECD government bonds held by insurance companies and investment funds. Unlike investment funds, insurance companies exhibit a clear rightward shift in the entire maturity distribution of their bond holdings toward lower maturities. In fact, while German investment funds increased their holding of some medium-term maturities, such as in the five to 10 years segment, the nominal values of maturities of 20 years or longer have declined. One interpretation is that investment funds have focused their purchases on bonds in particularly liquid market segments, especially in the 10-year maturities.

4.4 Non-linearity of insurer bond demand in duration

Standard demand theory predicts a downward sloping demand curve – eg a negative relationship between a bond price and quantity demanded. However, as the examples based on our illustrative model of liability-driven demand for bond has shown, under certain conditions – specifically when duration is high due to a significant fall in interest rates – demand for bond can actually be increasing in bond price. Such perverse demand conditions can lead to a feedback loop, whereby falling long-term yields induces duration-matching investors to buy

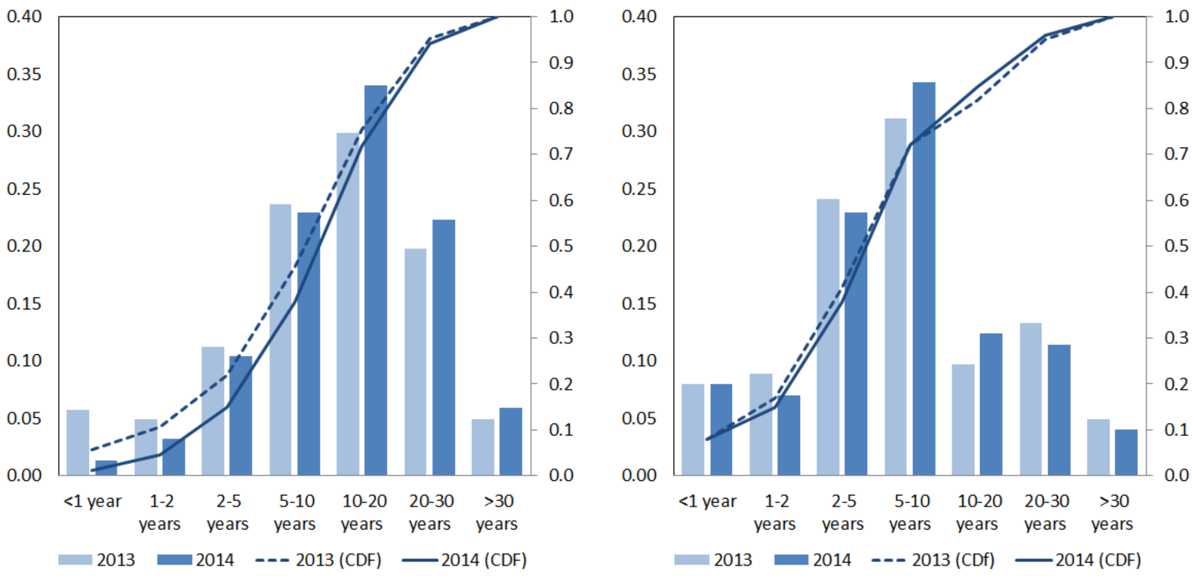

Figure 9: Holdings of OECD government bonds:percentage holdings in each maturity bucket and the cumulative distributions; insurance companies (left) vs investment funds (right); nominal values.

more long-term bonds, thereby driving yields even lower and feeding into further demand.

Figures 10 and 11 show the relationship between $\Delta y_t^{i,T}$ and $\Delta p_t^{i,T}$ using scatter plots, where each data point corresponds to a bonds issued by sector $i =$ (bunds, other euro area governments or non-euro area OECD government bonds) of maturity T at time t. For these charts we give greater weighted to quantity changes of longer duration bonds by multiplying $\Delta y_t^{i,T}$ by $D_t^{i,T}$.

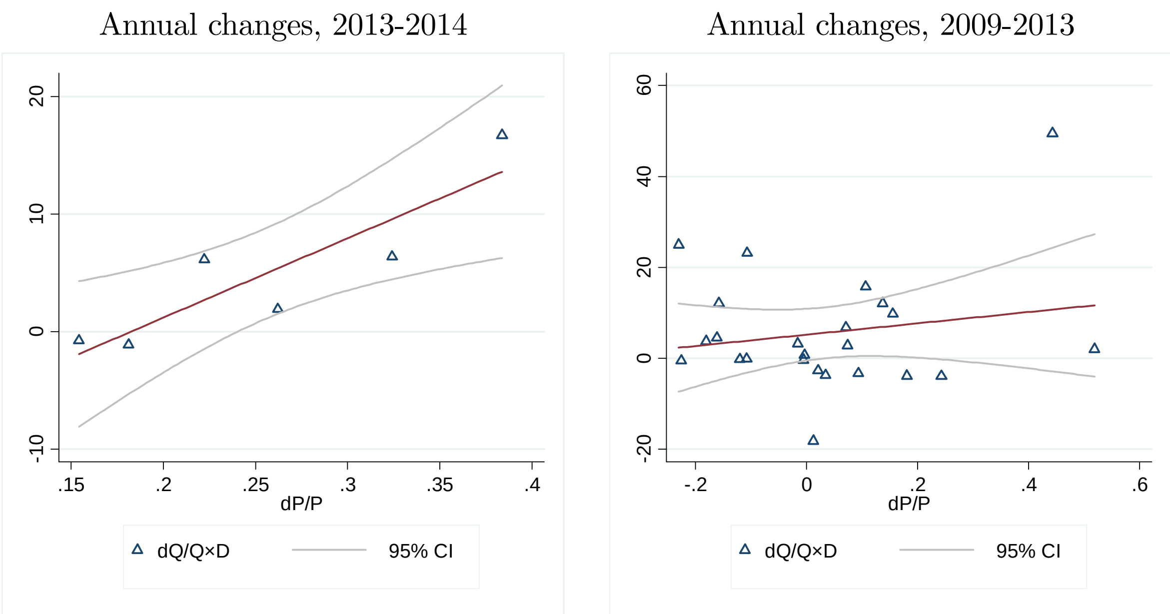

Figure 10: Demand elasticity (duration weighted), long-term government bond holdings of German insurance sector; OECD government bonds, >10 year durations.

Figure 10 focuses on longer duration bonds, $D_t^{i,T} > 10$ years. As the left-hand panel shows, the one-year period from end-2013 to end-2014, which saw a dramatic fall in long-term yields and a rapid rise in the duration of liabilities of German insurance companies (see above), is characterised by a positive fit to the scatter plot, indicating higher demand for bonds with a greater increase in price. This result is robust to using marked data from generic government bond yields rather than yields imputed from nominal and market values of insurer portfolio holdings, see Figure **??** in the Appendix. Similar dynamics are also observed for bonds with durations less than 10 years, Figure 11, but are less pronounced. In contrast, these shorter duration bonds exhibit a more familiar negative relationship between quantity and price changes during the preceding years, Figure 11, right-hand panel. The results are qualitatively similar when un-weighted $\Delta y_t^{i,T}$ is considered, Figures 13 and 14, or when quantity changes are weighted by time-to-maturity instead, $\Delta y_t^{i,T} \times T$, Figures 15 and 16 in the Appendix.

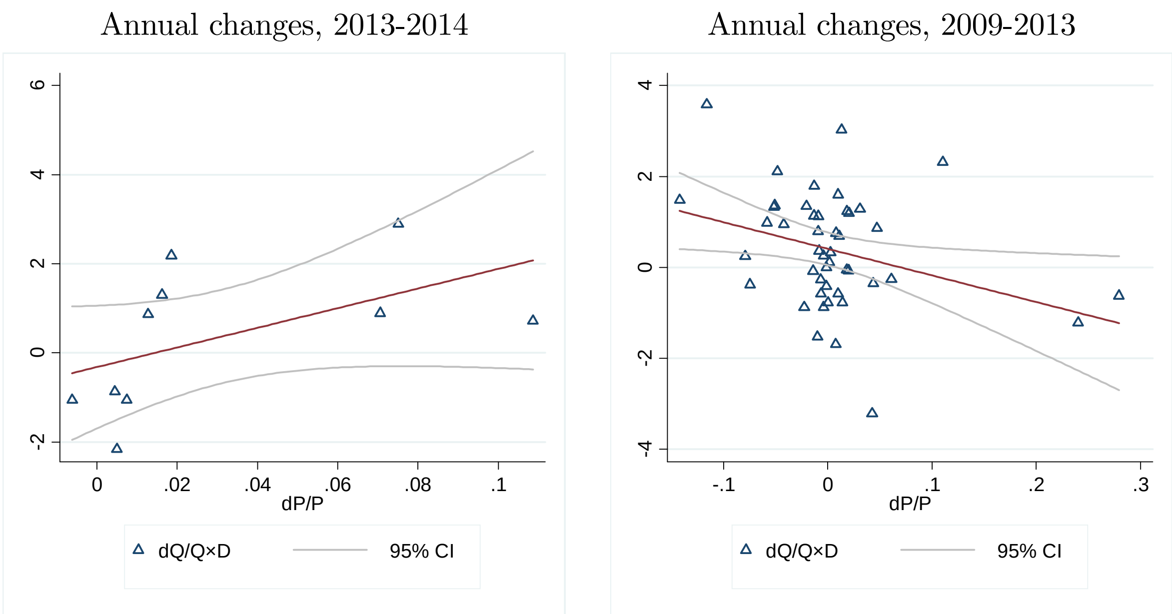

Figure 11: Demand elasticity (duration weighted), long-term government bond holdings of German insurance sector; OECD government bonds, <10 year durations.

More formally, we use a series of simple regressions to estimate price elasticity of bond demand by German insurance sector for bonds issued by sector i of maturity m at time t, where the cross sectional unit is the (i, T) pair:

$$\Delta y_t^{i,T} = \alpha + \beta \Delta p_t^{i,T} + \varepsilon_t^{i,T}, \tag{20}$$

where $i =$ (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); $T =$ ($<$ 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); and $t =$ 2009-2014. Table 1 shows the results. The full sample regression coefficient β, shown in column (1), is positive, opposite of what a standard deman theory would predict, indicating an upward sloping demand curve.

Our hypothesis predicts that such perverse sign on the price elasticity of bond demand would arise due to hunt for duration, hence should be characteristic of longer duration bonds. Splitting the sample into bonds with duration below and above 10 years, we find that the positive price elasticity estimate is driven by the longer duration subsample, Table 1 columns (2) and (3). Thus, consistent with scatter plots in Figures 10 and 11, the subsample regression based on equation (1) point at the significant role of duration in determining the sign of the slope of demand curve for fixed income securities by the insurance sector. The non-linear relationship between price elasticity of bond demand and bond duration can be gleaned more accurately by introducing the corresponding interaction term:

$$\Delta y_t^{i,T} = \alpha + \beta_0 \Delta p_t^{i,T} + \beta_1 D_t^{i,T} + \beta_2 (\Delta p_t^{i,T} \times D_t^{i,T}) + \varepsilon_t^{i,T}, \tag{21}$$

where $D_t^{i,T}$ is the McCauley duration for each bond category and maturity bucket computed from changes in the book value and the market value of insurance sector bond holdings. Column (4) in Table 1 shows the results. The coefficient on the linear change in price, β_0, is negative and statistically significant indicating a standard downward-sloping demand curve when controlling for duration. The regression coefficient estimate $\beta_0 = -1.258$ indicates that for a 1% increase in the price of a bond, quantity demanded falls by 1.3% on average, across all sector and maturities. However, a positive a statistically significant coefficient on the interaction term, β_2, indicates that for higher durations the relationship between changes in price and insurance sector demand for bond turns positive. The results are robust to controlling for the sector of issuance, indicating that the main driver of perverse relationship between prices and quantities demanded observed for parts of the same is bond duration. Positive coefficient on non-euro OECD and EME government bonds indicate German insurance sector purchases in excess of those predicted solely based on the yield (price) changes and duration.[17]

Table 2 shows analogous regression results for bond holdings by investment funds, column (2), as well as for bond holdings including also banks and households, column (3). The results shown in column (4) control for the investor sector rather than using subsample regressions. The results confirm that the interaction between duration and the slope of the demand curve for bonds is unique to the insurance sector, column (1). In contrast, investment funds exhibit

[17] The results are also robust to running simple OLS regressions on stacked data rather than random effects panel regressions, these are shown in Appendix Table 6. The main result for the interaction term also holds when we run fixed- rather than random-effects panel regression, Appendix Table 7. However, since the Hausman test fails to reject the null that the difference in coefficients between fixed- and random-effects specification is not systematic at the 5 percent level ($p-value$ 0.0820), and, moreover, since economically it makes little sense to assign individual intercepts to each cross-sectional unit because this is already done by controlling for duration and sector (sector group) of issuance, we focus on random-effects panel regression results. Replacing duration with bond maturity also yields qualitatively similar results, as one would expect, these are shown in Appendix Table 8.

Table 1: Relationship between bond demand and bond price, conditional on bond duration; panel regression results, dependent variable: pct change in bond nominal value.

	(1) full sample	(2) $D_t^{i,T} < 10$	(3) $D_t^{i,T} > 10$	(4) full sample	(5) full sample
$\Delta p_t^{i,T}$	0.606*	-1.012	0.691**	-1.258**	-1.281**
	(0.322)	(0.655)	(0.308)	(0.513)	(0.530)
$D_t^{i,T}$				0.003	0.004*
				(0.002)	(0.002)
$\Delta p_t^{i,T} \times D_t^{i,T}$				0.058***	0.056***
				(0.019)	(0.019)
Euro area					-0.020
					(0.055)
Non-euro OECD					0.144***
					(0.046)
Corporates					0.063
					(0.052)
EMEs					0.220**
					(0.100)
Constant	0.146***	0.126***	0.191***	0.119***	0.062
	(0.027)	(0.031)	(0.044)	(0.033)	(0.046)
Obs.	210	127	83	208	208
Cross-section	45	28	18	45	45

Cross-section determined by (i,T pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); T= (< 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 .

a more significant concentration into bonds issued by corporates and EME governments, and no effect of duration on their demand response to a change in price, column (2).

4.5 Have German insurers crossed the threshold?

Having detected the presence of non-linearity in the relationship between $\Delta y_t^{i,T}$ and $\Delta p_t^{i,T}$ which depend on $D_t^{i,T}$, the next step is to use a statistical test to credibly identify the threshold value of duration above which the insurance sector demand curve for bonds turns upward sloping in bond prices. We adopt a threshold estimation technique proposed by Hansen (2000):

$$\Delta y_t^{i,T} = \alpha + \beta_0 \Delta p_t^{i,T} I(D_t^{i,T} \leq \bar{D}) + \beta_1 \Delta p_t^{i,T} I(D_t^{i,T} > \bar{D}) + \varepsilon_t^{i,T} \tag{22}$$

$$= \begin{cases} \alpha + \beta_0 \Delta p_t^{i,T} + \varepsilon_t^{i,T} & if \ D_t^{i,T} \leq \bar{D} \\ \alpha + \beta_1 \Delta p_t^{i,T} + \varepsilon_t^{i,T} & if \ D_t^{i,T} > \bar{D} \end{cases}, \tag{23}$$

where $I(\bullet)$ is an indicator function and $\bar{D}$ denotes the threshold parameter to be estimated. Hansen (2000) derived an asymptotic approximation to the distribution of the least-squares estimate of the threshold parameter. Specifically, conditionally on the value of $\bar{D}$ it is possible to compute the sum of squared errors, $S(\bar{D}) = \sum_{i,T,t} (\hat{\varepsilon}_t^{i,T}(\bar{D}))^2$. The threshold parameter $\bar{D}$ is then estimated by minimizing the sum of squared $S(\bar{D})$: $\hat{D} = ArgMin_{\bar{D}} S(\bar{D})$.

Table 2: Relationship between bond demand and bond price, conditional on bond duration; panel regression results, dependent variable: pct change in bond nominal value.

	(1) Insurance companies	(2) Investment funds	(3) All non-insurer investors	(4) All investors
$\Delta p_t^{i,T}$	-1.281**	-0.297	0.816	0.661
	(0.530)	(0.668)	(1.024)	(0.883)
$D_t^{i,T}$	0.004*	0.004*	0.004	0.004
	(0.002)	(0.002)	(0.005)	(0.004)
$\Delta p_t^{i,T} \times D_t^{i,T}$	0.056***	-0.010	-0.007	-0.004
	(0.019)	(0.022)	(0.019)	(0.016)
Euro area	-0.020	-0.010	0.115	0.085
	(0.055)	(0.043)	(0.093)	(0.073)
Non-euro OECD	0.144***	0.109**	0.107**	0.109***
	(0.046)	(0.047)	(0.047)	(0.037)
Corporates	0.063	0.093*	0.047	0.105***
	(0.052)	(0.050)	(0.038)	(0.039)
EMEs	0.220**	0.221***	0.088	0.111*
	(0.100)	(0.049)	(0.067)	(0.058)
Insurance companies				0.145***
				(0.046)
Investment funds				0.081*
				(0.046)
Banks				-0.105***
				(0.033)
Constant	0.062	0.011	-0.081	-0.108**
	(0.046)	(0.040)	(0.073)	(0.042)
Obs.	208	239	701	909
Cross-section	45	49	144	189

Cross-section determined by (i,T) pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); m= (< 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 .

Table 3: Relationship between bond demand and bond price, conditional on bond duration; threshold regression following Hansen (2000), dependent variable: pct change in bond nominal value

	(1) $D_t^{i,T} \leq \bar{D}$	(2) $D_t^{i,T} > \bar{D}$	(3) $D_t^{i,T} \leq \bar{D}$	(4) $D_t^{i,T} > \bar{D}$
$\Delta p_t^{i,T}$	-.959**	0.716**	-1.009**	0.876**
	(0.492)	(0.333)	(0.492)	(0.391)
Euro			-0.020	-0.039
			(0.094)	(0.118)
non-euro OECD			0.120	0.091
			(0.196)	(0.228)
Corp.			-0.012	0.177
			(0.083)	(0.109)
EME			0.305*	-0.145
			(0.180)	(0.171)
Constant	0.125***	0.196***	0.087	0.124
	(0.027)	(0.062)	(0.068)	(0.089)
Obs.	145	64	129	80
R-squared	0.014	0.112	0.062	0.183
Threshold $\hat{D}$	15.644		13.836	
Bootstrap p-value	0.056		0.005	

Cross-section determined by (i,T) pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); T= ($<$ 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and $>$30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p$<$0.01, ** p$<$0.05, * p$<$0.1.Threshold regression estimation routine follows Hansen (2000), with threshold estimated using 2000 bootstrap replications and allowing for heteroskedastic errors (White-corrected).

Table 3 and Figure 12 show the results. For the baseline specification which does not control for the sector of issuance, the threshold duration $\bar{D}$, estimated using 2,000 bootstrap replications and allowing for heteroskedastic standard errors, equals 15.6, significant at the 10 percent level (Table 3 columns (1) and (2), and Figure 12, left-hand panel). When the duration is below this value, the insurance sector bond demand is decreasing in price, column (1), whereas when bond duration exceeds the threshold, the demand increase in price, column (2).

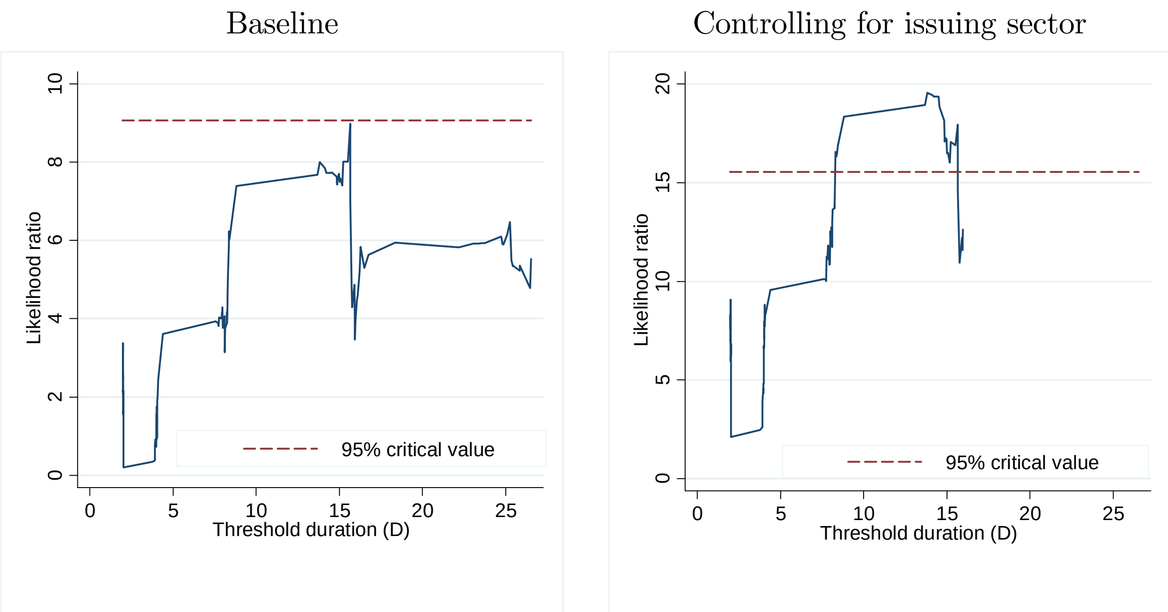

Figure 12: F-test for threshold duration (D): reject linearity if F sequence exceeds critical value.

Focusing on the results which control also for the issuance sector (Table 3 columns (3) and (4) and Figure 12, right-hand panel) the null of no threshold is rejected at 1 percent significance level (p-value of 0.005). The threshold duration $\bar{D}$ above which the demand curve for bonds by the insurance sector becomes upward sloping is estimated at 13.84. Below this threshold level, the demand curve is downward sloping, with $\Delta y_t^{i,T}$decreasing almost one-for-one ($\beta_0 = -1.01$) with price, $\Delta p_t^{i,T}$. Above the threshold duration of 13.84, however, the relationship between bond nominal holdings and price reverses ($\beta_1 = 0.88$), with a one percentage point increase in price, $\Delta p_t^{i,T}$, associated with 0.88 percent increase in the nominal value of bond holdings, $\Delta y_t^{i,T}$. Given that the aggregate portfolio duration of

German insurers increased from 11 to 14 from 2013 to 2014, with the duration of eurozone government bond holdings rising from 14 to 18, our findings suggests that the insurance sector may have entered a regime of self-feeding hunt for duration as government bond yields in the euro area continued to fall.

5 Implications for bond markets and yields

5.1 Addressing reverse causality

As with any regression of quantities on prices, endogeneity is a primary concern. In particular, given the low (quarterly) frequency of our data, one concern is that the regression results given in Tables 1 and 2 arise exclusively due to the effect of $\Delta y_t^{i,T}$ on $\Delta p_t^{i,T}$ and not due to the response of $\Delta y_t^{i,T}$ to movements in $\Delta p_t^{i,T}$, as the duration hunt channel would predict for bonds with long duration. In order to address the possible issue of reverse causality, we use three-stage least squares to estimate the following simultaneous equations model:

$$\Delta y_t^{i,T} = \alpha + \beta_0 \Delta p_t^{i,T} + \beta_1 D_t^{i,T} + \beta_2 (\Delta p_t^{i,T} \times D_t^{i,T}) + \beta_3 Z_t^i + \varepsilon_t^{i,T}, \tag{24}$$

$$\Delta p_t^{i,T} = \delta + \gamma_0 \Delta y_t^{i,T} + \gamma_1 D_t^{i,T} + \gamma_2 (\Delta y_t^{i,T} \times D_t^{i,T}) + \gamma_3 Z_t^i + \nu_t^{i,T}, \tag{25}$$

where $\Delta y_t^{i,T}$ and $\Delta p_t^{i,T}$ are endogenous, while $D_t^{i,T}$, the interaction terms with $D_t^{i,T}$ and any additional variables included in Z_t^i are assumed to be exogenous and are used as instruments in the first stage of the estimation. In addition, the firststage estimation includes insurance sector dummy as an instrument.

Table 4, shows the results. Specification (1) only includes $D_t^{i,T}$, the interaction terms with $D_t^{i,T}$ and insurance sector dummy in the list of instruments, while specification (2) also includes indicator variables for the issuer category of the bonds. The estimated coefficients in the $\Delta y_t^{i,T}$ equations, shown in the first and third columns, are consistent with the results reported in Tables 1 and 2, above, in that the linear association between $\Delta y_t^{i,T}$ and $\Delta p_t^{i,T}$ is negative, as conventional upwardsloping demand would predict, but turns positive once $\Delta p_t^{i,T}$ is interacted with $D_t^{i,T}$ and is also increasing in the level of $D_t^{i,T}$, supporting the duration

Table 4: Simultaneous equations estimation results for bond demand and bond price, Conditional on bond duration.

	(1)		(2)	
	$\Delta y_t^{i,T}$	$\Delta p_t^{i,T}$	$\Delta y_t^{i,T}$	$\Delta p_t^{i,T}$
$\Delta p_t^{i,T}$	-10.488*		-16.772***	
	(5.555)		(6.218)	
$\Delta p_t^{i,T} \times D_t^{i,T}$	0.205*		0.325***	
	(0.106)		(0.118)	
$\Delta y_t^{i,T}$		-7.098***		-6.705***
		(1.013)		(0.894)
$\Delta y_t^{i,T} \times D_t^{i,T}$		0.151***		0.143***
		(0.024)		(0.022)
$D_t^{i,T}$	0.010***	0.001	0.013***	0.002
	(0.003)	(0.004)	(0.004)	(0.004)
Euro			0.072	0.048
			(0.084)	(0.152)
Non-euro OECD			0.110	0.521***
			(0.103)	(0.195)
Corp.			-0.082	0.103
			(0.096)	(0.151)
EME			-0.161	0.563***
			(0.143)	(0.190)
Constant	0.055	0.305***	0.086	0.090
	(0.041)	(0.090)	(0.091)	(0.136)
Insurance dummy in first stage	Yes	Yes	Yes	Yes
Obs.	909	909	909	909

Cross-section determined by (i,T pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); T= (< 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 . Simultaneous equations for $\Delta y_t^{i,T}$ and $\Delta p_t^{i,T}$ estimated using three-stage least squares. All other variables treated as exogenous. Insurance sector dummy used in the first stage as an instrument.

hunt hypothesis. In addition, as expected, the coefficients on $\Delta y_t^{i,T}$ are significant in the $\Delta p_t^{i,T}$ equations, second and fourth columns. At the same time, there is no linear association between $D_t^{i,T}$ and $\Delta p_t^{i,T}$ which again suggests that a rise in duration affects bond yields only by the virtue of being a driver of insurance sector bond purchases.

In sum, a robustness check of the relationship between bond holdings and bond prices using a simultaneous equations model indeed supports a two-way causality, but rejects reverse causality from bond purchases to bond prices as the sole driver of the results.

5.2 Insurer portfolio duration as an asset pricing factor

As long as bond markets are not completely frictionless, such hunt for duration by the insurance sector would be expected to affect bond prices and yields. Vayanos and Vila (2009) provide a theoretical framework in which fluctuations in investor demand for bonds affect prices and yields even if instantaneous risk-free rates remain unchanged. Such effects would arise in the presence of frictions that limit arbitrage across bonds of different risk characteristics due to, for example, preferred habitat demand by insurance companies for bonds of particular maturities. The term structure of interest rates is then determined by the interaction between various preferred habitat investors and risk-averse arbitrageurs, who, in turn, demand compensation for bearing interest rate risk. Hence, the associated empirical literature that followed identified investor exposure to duration risk as a key asset pricing factor in fixed income markets (see, e.g., Hanson (2014), Haddad and Sraer (2015), and Malkhozov et al (2015)).

Since most such studies have focused on US markets, where the bulk of the exposure to negative balance sheet convexity and duration risk is borne by MBS investors, MBS duration has been consistently identified as a key factor driving bond excess returns and risk premia. In contrast, our hypothesis is that in euro area, or at least in Germany, exposure to negative balance sheet convexity and duration risk is concentrated among liability-driven institutional investors such as insurance companies. Hence, balance sheet duration of insurer bond holdings may exert analogous impact on German government bond yields as does the duration exposure of MBS investors on Treasury yields in the US.

In this sub-section, we broadly follow the framework of these studies by testing the (predictive) relationship between the duration and bond excess returns. Due to the small sample size, we also explore variation across bond maturities, implicitly allowing for market segmentation. Given that we have estimates of $D_t^{i,T}$ for maturity buckets of one to two years, two to five years, five to 10 years, 10 to 20 years, 20 to 30 years, and greater than 30 years, we use market data to obtain excess returns for government bonds in the euro area of similar maturities. First, we obtain the zero-coupon rate curve up to 30-year maturity from benchmark bund yields and euro swap rates using standard term structure models.[18] Next, for each maturity, T, we compute the log holding period return from buying a T- year bond at time t and selling it as a $T-1$ year bond at time $t+1$ as: $rhp^T_{t\to t+1} = \ln(P^{T-1}_{t+1}) - \ln(P^T_t)$; where $P^T_t = \exp\left(-T \times r^T_t\right)$. Bond excess returns over a 1-year horizon are then computed as $rx^T_{t\to t+1} = rhp^T_{t\to t+1} - r^1_t$. The six maturity buckets in our data on bond holdings are then matched with one-year excess returns from investing in the following maturities $T =$ two, five, 10, 15, 20, and 30 years. We then estimate the following predictive equation using annual data from 2010 to 2014 for the duration of holdings within each bucket and one-year excess returns sampled at the end of the first quarter in years 2011 through 2015:

$$rx^T_{t\to t+1,+1Q} = \alpha + \beta_0 D_t^{T,INSURANCE} + \beta_1 D_t^{T,BANKS} + \beta_2 D_t^{T,FUNDS} + \varepsilon^T_t, \qquad (26)$$

where, the dependent variable, $rx^T_{t\to t+1,+1Q}$, is the excess return sampled at end-$Q1$ of the following year (that is sampled three months after the corresponding year t bond holdings duration data). The explanatory variables include not only the duration of German insurance sector holdings, $D_t^{T,INSURANCE}$, but also the duration of holdings of German banks, $D_t^{T,BANKS}$, and investment funds, $D_t^{T,FUNDS}$. This is because a-priori we do not know which sector(s) represent the marginal investors whose exposure to interest rate risk (ie duration) is the best predictor of bond excess returns.

Table 5, column (1) shows the results for German government bonds (due to the narrow focus on bunds, the number of observations drops significantly). Only the coefficient on the duration of insurance sector holdings, $D_t^{T,INSURANCE}$, is signficant, indicating that a unit rise in the duration of bond holdings within each maturity bucket is associated with 13.9% higher one-year excess returns at the end of the first quarter of the following year

[18] We use the Nelson-Siegel four factor model for German zero-coupon rate curve and a spline method for zero-coupon rate curve derived from euro swap rates.

Table 5: Response of bond excess returns and future realized yields to the duration of bond holdings of German insurance companies, banks, and investment funds..

	(1)	(2)	(3)	(4)
	Bund yields		plus euro swap rates	
Dependent variable:	$rx^T_{t\to t+1,+1Q}$	$r^T_{t+1,+1Q}$	$rx^T_{t\to t+1,+1Q}$	$r^T_{t+1,+1Q}$
$D_t^{T,INSURANCE}$	0.139**	-0.012**	0.013	-0.003**
	(0.057)	(0.005)	(0.023)	(0.001)
$D_t^{T,BANKS}$	0.014	-0.008	-0.015	-0.000
	(0.102)	(0.008)	(0.019)	(0.001)
$D_t^{T,FUNDS}$	-0.142	0.021*	0.006	0.004**
	(0.150)	(0.012)	(0.029)	(0.002)
Constant	-0.007	0.006*	0.033**	0.009***
	(0.024)	(0.003)	(0.016)	(0.002)
Obs.	25	25	54	54
R-squared	0.501	0.456	0.211	0.326

Cross-section determined by (i,T pair; i= (bunds, other euro are governments); T= (1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing) for bond holdings duration; Q1 2011 to Q1 2015 sample period for zero coupon yields and excess returns; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 .

(three months ahead). This suggests that changes to the duration of the bunds portfolio of German insurance companies significantly predict future excess returns on bunds. Note that the excess returns could rise owing to higher term spreads in period t or due to lower future yields in period $t+1$. To see this, simply express $rx^T_{t\to t+1}$ in terms of yields rather than prices: $rx^T_{t\to t+1} = T \times (r^T_t - r^1_t) - (T-1) \times (r^{T-1}_{t+1} - r^1_t)$.

When we replace excess returns with the corresponding bond yields at the end of the first quarter of year $t+1$, we indeed observe a negative and significant impact of the duration of insurance sector bond holdings on future realised German government bond yields, column (2) in Table 5. The coefficient of -0.012** on $D^{T,INSURANCE}_t$ indicates that a unit rise in the duration of bond holdings during year t is associated with bund yields that are 120 basis points lower at the end of the first quarter of year $t+1$.

In contrast to the coefficient on insurance sector bond portfolio duration, the coefficient on the duration of bond holdings by German investment funds,$D^{T,FUNDS}_t$, is positive, indicating that a higher duration of the bond holdings of investment funds tended to be followed by higher corresponding bond yields.

Columns (3) and (4) of Table 5 repeat the analysis adding the duration of euro area government bond holdings and the corresponding excess returns and yield metrics to the sample. Here, the additional dependent variables are constructed from zero-coupon rates derived from euro swap rates. Since we do not have data on institutional investors outside of Germany, it is not surprising that we do not detect a similar impact for this broader metric of euro area-wide bond excess returns. Still, the negative coefficients on $D^{T,INSURANCE}_t$ in the expanded sample regressions with euro swap rates, column (4), are consistent with regressions where only German government bond yields are used, albeit smaller in magnitude.

In sum, although based on a small sample size, the regression results reported in Table 5 provide some suggestive evidence that the hunt for duration by the German insurance sector was a factor driving bund excess returns up and future realized bund yields down. However, more empirical work, using richer data, would be needed to credibly test for the asset pricing effects of insurers' duration exposure.

6 Conclusion and policy implications

This paper has examined the consequences of mismatches in the duration of assets and liabilities of insurance companies for bond market dynamics. Due to negative convexity, the duration gap becomes increasingly negative for any given portfolio of bond holdings. Risk management or regulatory constraints on duration risk create incentives for insurers to extend the duration of bond portfolios in order to contain negative duration gaps.

We have shown that this hunt for duration may amplify declines in long-term interest rates. When long-term rates fall, the demand for long-term fixed income securities by insurance firms increases, possibly adding to downward pressure on long-term rates. As a consequence, duration gaps tend to widen further, eliciting additional purchases of longer-dated bonds. If this amplification mechanism is sufficiently strong, for instance because insurance companies' purchases constitute a large share of total demand, a feedback loop may develop.

Our empirical investigation, using data provided by the Deutsche Bundesbank, has highlighted several features that corroborate key elements of our narrative. First, we have shown that German insurance firms added substantially to their fixed income portfolios during the period of rapidly declining long-term interest rates. In 2014, insurance firms accounted for around 40 percent of the net purchases of government bonds by German residents—a disproportionate increase considering that insurance firms hold only around 12 percent of all bonds held by German residents. Second, the maturity of insurers' bond portfolios has increased substantially. Third, looking at the period ranging from 2009 to 2014, German insurance firms have tended to exhibit an abnormally strong demand response to a change in the price of long-duration bonds; that is they demanded more bonds with higher duration when their prices (yields) were rising (falling). Fourth, we do not observe a comparable increase in the maturity of bond portfolios, or a perverse demand response to duration, for other sectors with significant bond portfolios. Taken together, the evidence is consistent with higher demand for long-term bonds by insurance firms that have to contain asset– liability mismatches stemming from negative duration gaps. Fifth, and related, tentative results point to the duration of bond holdings of German insurance firms as an asset pricing factor in German government bond markets, akin to the duration of MBS investors driving US

Treasury yields. In that context, higher duration predicts higher excess returns and lower realised future yields of German government bonds. We do not find similar effects for the duration of bond holdings in other sectors. However, further investigation with richer data would be needed to credibly establish the asset pricing implication of duration hedging by insurance firms in the euro area.

We have not attempted to develop a general equilibrium model of the determinants of German long-term interest rates. Nevertheless, some insights may still be gained from a qualitative analysis. For instance, our approach may hold promise in explaining differences in the transmission channels and market impacts of QE in the euro area and the USA. One difference concerns the composition of bond markets. Fixed income markets in the euro area are dominated by government bonds, while corporate bond markets are relatively small. At the same time, euro area government bond markets are more fragmented than the US Treasury market. Hence, a reduction in the supply of government bonds of the same size may have a relatively stronger impact on government bond yields in the euro area. Second, the investor base differs, with European insurance companies holding a large part of their portfolios in government bonds. In contrast, insurance companies in the USA hold corporate bonds and MBS rather than government bonds. Hence, risk management and regulations that governs portfolio allocation decisions may be of greater significance for yield dynamics in government bond markets in the euro area.

How could policymakers contain a negative feedback loop between negative duration gaps and compression of long-term interest rates?[19] One possible response would be for insurance regulators to alleviate the duration constraint, for instance by allowing adjustments to the discount factors used to value insurance liabilities. However, such regulatory intervention would raise a number of issues. One is calibrating the magnitude and duration of adjustments. Another question is whether regulatory adjustment might at some point conflict with internal risk management aiming at limiting duration gaps. In this case, the effectiveness of regulatory measures might be limited if firms were to match duration due to risk management reasons irrespective of relaxation of regulatory rules that requires them to match

[19] In the long run, life insurers can reduce, or eliminate, negative duration gaps by adjusting insurance contracts, e.g. through lower contractually guaranteed returns or move away from products with fixed guaranteed rates altogether. Such an adjustment may raise different policy issues.

duration. In any case, discretionary regulatory intervention that works through a deliberate weakening of risk management standards would conflict with broader regulatory goals of strengthening risk management systems within firms.

Another possibility would be for monetary policy to take account of the feedback loop documented in our paper. The hunt for duration discussed in this paper occurred against the backdrop of firming market expectations of largescale asset purchases by the ECB. In turn, the negative feedback loop between negative duration gaps and compression of long-term interest rates may affect the cost-benefit assessment of large-scale asset purchases. On the one hand, the steepening of the market demand curve for long-duration bonds makes central banks asset purchases more effective. On the other hand, the feedback loop may entail additional financial stability risks, by inducing insurers to lock in very low long-term interest rate exposures, or by encouraging position-taking by other market participants that employ momentum trading or other short-term strategies. Monetary policy might factor these changing trade-offs into its assessment of unconventional policies. More fundamentally, there may be questions about the optimal design of central bank balance sheet polices in the presence of negative feedback loops, including for instance the composition of asset purchase programmes, and a possible role of yield levels, or term premiums, as operational targets.

Against this backdrop, we view our analysis as a first step that can be taken further in several directions. One avenue would be to analyse firm-level portfolio data to utilise the additional statistical power coming from cross-sectional information. More broadly, our analysis suggests that our approach to the determination of long-term interest rates using the liabilities-driven model of portfolio choice may hold promise in quantifying the impact of central bank asset purchases for overall market conditions. Not least, our approach would also open up the possibility of contributing to an understanding of why long-term rates may overshoot so far on the way down. This overshooting may also make them susceptible to a sharp reversal and snap-back, as they did in the second half of April 2015. Indeed, there is evidence that market positioning had become onesided in the run-up to this episode, likely due to the complementary actions of other market participants trading on falling yields.[20]

[20]See BIS (2015b, c) for the discussion of market positioning and volatility during the bund tantrum.

A Appendix

In this appendix, we present supplementary scatter plots contrasting the demand response from end-2013 to end-2014 and contrasting it with the demand responses in the previous three years.

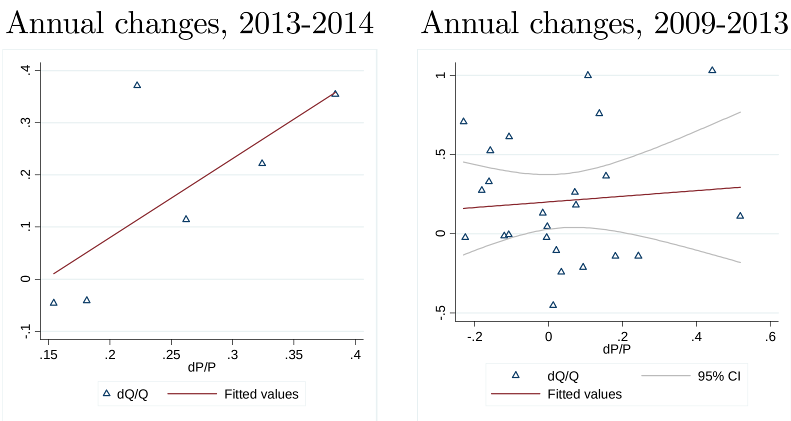

Figure 13: Demand elasticity, long-term government bond holdings of German insurance sector; OECD government bonds, >10 year maturities.

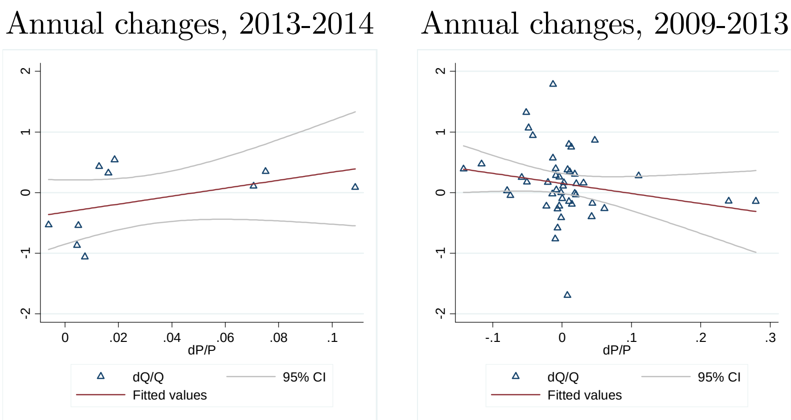

Figure 14: Demand elasticity, long-term government bond holdings of German insurance sector; OECD government bonds, <10 year maturities.

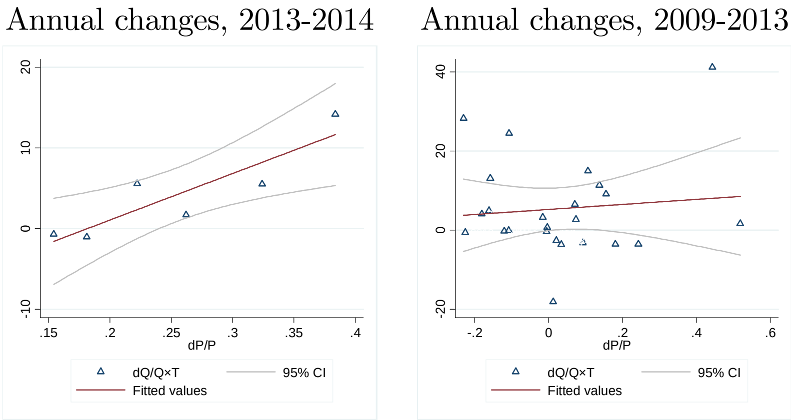

Figure 15: Demand elasticity (maturity weighted), long-term government bond holdings of German insurance sector; OECD goverment bonds, >10 year maturities.

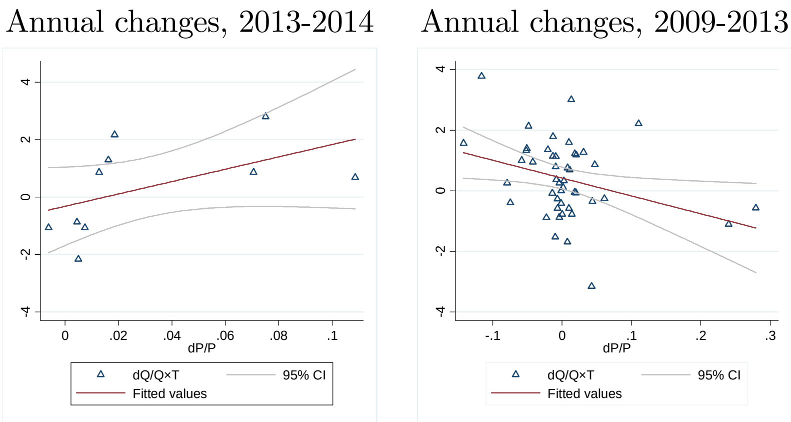

Figure 16: Demand elasticity (maturity weighted), short- and medium-term government bond holdings of German insurance sector; OECD government bonds, <10 year maturities.

Table 6: Relationship between bond demand and bond price, conditional on bond duration; stacked OLS regression results, dependent variable: pct change in bond nominal value.

	(1) full sample	(2) $D_t^{i,T} < 10$	(3) $D_t^{i,T} > 10$	(4) full sample	(5) full sample
$\Delta p_t^{i,T}$	0.606	-1.012*	0.691*	-1.258***	-1.281***
	(0.384)	(0.560)	(0.384)	(0.449)	(0.468)
$D_t^{i,T}$				0.003	0.004
				(0.003)	(0.003)
$\Delta p_t^{i,T} \times D_t^{i,T}$				0.058***	0.056***
				(0.018)	(0.017)
Euro area					-0.020
					(0.074)
Non-euro OECD					0.144
					(0.162)
Corporates					0.063
					(0.069)
EMEs					0.220
					(0.145)
Constant	0.146***	0.126***	0.191***	0.119**	0.062
	(0.033)	(0.044)	(0.046)	(0.051)	(0.066)
Obs.	210	127	83	208	208
R-squared	0.031	0.012	0.110	0.090	0.117

Cross-section determined by (i,T) pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); T= (< 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 .

Table 7: Relationship between bond demand and bond price, conditional on bond maturity; fixed-effects panel regression results, dependent variable: pct change in bond nominal value.

	(1) full sample	(2) $D_t^{i,T} < 10$	(3) $D_t^{i,T} > 10$	(4) full sample
$\Delta p_t^{i,T}$	0.475*	-0.966	0.664*	-0.857
	(0.281)	(0.754)	(0.380)	(0.572)
$D_t^{i,T}$				-0.253***
				(0.050)
$\Delta p_t^{i,T} \times D_t^{i,T}$				0.137***
				(0.017)
Constant	0.151***	0.125***	0.193***	3.215***
	(0.034)	(0.006)	(0.030)	(0.609)
Obs.	210	127	83	208
Cross-section	45	28	18	45
R-squared	0.017	0.012	0.100	0.095

Cross-section determined by (i,T) pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); T= (< 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 .

Table 8: Relationship between bond demand and bond price, conditional on bond duration; panel regression results, dependent variable: pct change in bond nominal value

	(1) full sample	(2) $T_t^{i,} < 10$	(3) $T_t^{i,} > 10$	(4) full sample	(5) full sample
$\Delta p_t^{i,T}$	0.606*	-0.991	0.665**	-0.575	-0.619
	(0.322)	(0.654)	(0.313)	(0.610)	(0.586)
$T_t^{i,T}$				0.004*	0.005**
				(0.002)	(0.002)
$\Delta p_t^{i,T} \times T_t^{i,}$				0.046*	0.045*
				(0.027)	(0.026)
Euro area					-0.010
					(0.057)
Non-euro OECD					0.146***
					(0.046)
Corporates					0.065
					(0.053)
EMEs					0.193*
					(0.107)
Constant	0.146***	0.119***	0.205***	0.101***	0.040
	(0.033)	(0.042)	(0.035)	(0.047)	(0.047)
Obs.	210	129	81	210	210
Cross-section	45	28	17	45	45

Cross-section determined by (i,T) pair; i= (bunds, other euro are governments, non-euro area OECD, non-OECD (eg EMEs), non-financial corporates, banks, and other); T= (< 1 years, 1-2 years, 2-5 years, 5-10 years, 10-20 years, 20-30 years, and >30 year maturities); 2010-2014 sample period (2009 discarded by first differencing; robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 .

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