Interest Rate Risk Management in Uncertain Times*

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Abstract

We revisit the evidence on real effects of uncertainty shocks in the context of interest rate uncertainty, which can readily be hedged in the interest rate swap market. We document that adverse movements in interest rate uncertainty predict significant slowdowns in real activity, both at the aggregate and at the firm-level. To understand how firms cope with interest rate uncertainty, we develop a dynamic model of corporate investment, financing and risk management and test it using a rich dataset on corporate swap usage. Our results suggest that interest rate uncertainty depresses financially constrained firms' investment in spite of hedging opportunities, as for these firms risk management by means of swaps is, effectively, risky.

Keywords: interest rate uncertainty, volatility, risk management, interest rate swaps, financial frictions, corporate investment

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1 Introduction

A large literature in macro-finance documents adverse effects of uncertainty shocks on future economic activity, using a variety of uncertainty proxies, such as policy uncertainty (Baker, Bloom, and Davis (2016)) or statistical measures of broad macroeconomic uncertainty (Jurado, Ludvigson, and Ng (2015)). Our focus in this paper is on uncertainty about the future path of interest rates, or interest rate uncertainty, for short. Interest rate uncertainty, in contrast to many other manifestations of uncertainty, can readily be hedged in the financial derivatives market, for example, through interest rate swaps. Daily trading volume in interest rate swaps – $2.7 trillion as of December 2016 – dwarfs other asset classes as a sizable fraction of US firms makes use of these derivatives to hedge their interest rate risk exposure. In this paper, we revisit the evidence regarding adverse effects of uncertainty on real activity in the context of hedging interest rate uncertainty.

Interest rate uncertainty reflects both uncertainty about future economic activity and about future actions of the monetary authority. Figure 1 depicts a proxy of interest rate uncertainty, TIV, an implied volatility index from Treasury future options together with the economic policy index of Baker, Bloom, and Davis (2016). We note that while both series indeed feature a strong countercyclical component, the interest rate uncertainty proxy displays distinct spikes around events related to monetary policy. For example, the interest rate uncertainty index jumps numerous times between 2001 and 2003, a period during which the Federal Reserve cut the target federal funds rate in several meetings. Increased monetary policy uncertainty has also been a key concern of policymakers during this period as emphasized, for example, in Chairman Greenspan's (2003) Jackson Hole speech.[1]

[insert Figure 1 here]

In this paper, we document novel links between interest rate uncertainty and real economic activity and the determinants of interest rate risk management of non-financial corporations, both theoretically and empirically. Our starting point is the empirical observation that various interest rate uncertainty proxies exhibit strong predictive power for real activity at the aggregate level. We interpret this evidence through the lens of a dynamic model that links interest rate uncertainty to firm-level investment, financing and risk management and ask, to what extent can firms effectively hedge interest

[1] Greenspan's opening remarks are: "Uncertainty is not just an important feature of the monetary policy landscape; it is the defining characteristic of that landscape."

rate uncertainty in the swap market? The model provides novel predictions in this regard, which we empirically test by means of a rich data set on interest rate swap usage, and thereby provide evidence on the cross-sectional determinants of corporate interest rate risk management.

In the data, we find that rises in interest rate uncertainty predict a significant slowing of future economic activity. Empirical proxies of interest rate uncertainty, such as TIV, a dispersion measure from forecasts of the three-month Treasury yield, and realized volatility measures of short-term yields, negatively predict future aggregate investment, as well as output and employment. These results also remain robust in predictive regressions upon inclusion of standard business cycle indicators and other uncertainty measures such as the VIX, the economic policy uncertainty measure of Baker, Bloom, and Davis (2016) or the financial uncertainty index by Jurado, Ludvigson, and Ng (2015). The estimated coefficients are also economically meaningful. For example, any one standard deviation change in interest rate uncertainty, translates to a \$25 billion ($= -0.365$ (estimated coefficient) $\times$\$68 (standard deviation of aggregate investment)) drop in aggregate investment.

Ultimately, fluctuations in aggregate activity reflect corporate policies in an environment with movements in interest rate uncertainty. We therefore further dissect our aggregate results at the firm-level by asking how interest rate uncertainty affects corporate investment decisions, especially when firms have access to the swap market. To guide the ensuing empirical investigation, we develop a dynamic, quantitative model of corporate investment, financing and risk management in the presence of interest rate uncertainty and financial frictions. The model is rich enough that it can be calibrated and simulated with the objective of generating testable predictions on the cross-sectional and time-series determinants of hedging and providing a benchmark against which empirical findings can be evaluated through counterfactuals.

Our setup extends recent dynamic models of corporate investment and financing with costly external finance (such as e.g., Gomes (2001), or Hennessy and Whited (2007)) with a fairly realistic interest rate environment. This amounts to specifying short rate dynamics exhibiting stochastic volatility so as to capture interest rate uncertainty, aggregate productivity shocks and volatility that drive long-term yields, as well accounting for the fixed versus floating rate mix in firms' debt structures. Critically, interest rate swaps provide an instrument to hedge stochastic movements in interest rates by exchanging floating rate payments linked to short rates with fixed swap rates, and vice versa. Swapping floating rate for fixed rate payments frees up resources for firms when interest rates suddenly rise, which is valuable for firms that would otherwise have to incur costs of external finance in high interest rate episodes, and vice versa.

Our model simulations confirm that rises in interest rate uncertainty come with significant declines in corporate investment. While this prediction is familiar from environments in which firms delay exercising investment options because of irreversibility (the classic real options effect), our counterfactuals indicate that firms primarily cut back on investment facing elevated uncertainty about floating rate payments stemming from debt financing (a cash flow effect). More specifically, our model predicts that in the cross-section smaller firms with more growth opportunities (i) rely more on short-term floating rate (bank) debt rather than long-term fixed rate (corporate) bonds, (ii) are more exposed to interest rate uncertainty so that they hedge more, (iii) but exhibit higher exposure even post-hedging so that they cut back more on investment even though hedging alleviates the adverse effects of interest rate uncertainty, and (iv) swap to fixed rate payments because floating rate debt leaves their financial needs concentrated in times when interest rates suddenly rise. Importantly, counterfactuals provide a simple explanation why firms tend to refrain from fully hedging their exposure in the swap market: risk management through swaps is effectively risky, especially for constrained firms, because, as much as swapping floating rates for fixed rates frees up resources when interest rates rise, opposite movements create financial commitments and push them closer to issuing costly equity, and default.

We test our model predictions and present further evidence on the determinants of interest rate risk management using a comprehensive data set on corporate interest rate swap usage. Our empirical results confirm that smaller and constrained firms tend to have higher exposure to interest rate risk and so hedge that more, but are left more exposed even after hedging, so that they reduce investment more in face of interest rate uncertainty, as do firms chiefly relying on bank and on floating rate debt. In contrast, investment of firms with minimal leverage only (the zero-leverage companies) is virtually unaffected by movements in interest rate uncertainty, reducing the relevance of real options effects in the context of interest rate uncertainty. Similarly, smaller and constrained firms tend to swap to fixed rate payments as their floating rate exposure leaves them vulnerable to sudden rises in interest rates. Overall, the empirical evidence is in line with the model prediction that adverse effects of interest rate uncertainty are driven by floating rate debt in firms' debt structure, which constrained firms refrain from fully hedging.

The rest of the paper is organized as follows. After the literature review, Section 2 reports our motivational regressions and discusses the data, while Section 3 presents a model of dynamic risk management together with a calibration. We empirically explore the model's predictions in Section 4, and conclude in Section 5.

Literature review: Our paper contributes to several strands of the literature. A small number of recent papers examines interest rate related risk management practices, both empirically and theoretically. Jermann and Yue (2014) examine the real effects of interest rate swaps in a quantitative general equilibrium model. In closely related work, Ippolito, Ozdagli, and Perez (2015) consider hedging in conjunction with floating rate debt in firms' debt structures, focusing on the transition mechanism of monetary policy to firms. Chernenko and Faulkender (2011) empirically explore the cross-section of swap usage, focusing on speculative motives for swap usage rather than real effects.

In contemporaneous and complementary work, Vuillemey (2015) develops a quantitative dynamic model of bank interest rate risk management. Similarly, Rampini, Viswanathan, and Vuillemey (2015) empirically study hedging for U.S. financial institutions and document a positive relation between net worth and hedging. Begenau, Piazzesi, and Schneider (2015) develop a novel approach to estimate banks' risk exposure due to their interest rate derivative positions. In contrast, our work examines swap usage of non-financials.

Our work is also related to the emerging literature on risk management in dynamic models. Rampini and Viswanathan (2010, 2013) build dynamic models of contracting frictions and show that hedging using state-contingent instruments may not be optimal for financially constrained firms. Bolton, Chen, and Wang (2011, 2012) and Hugonnier, Malamud, and Morellec (2015), examine corporate policies when firms can engage in risk management through derivatives and cash holdings. In similar setups, Lin, Wang, Wang, and Yang (2017) consider stochastic interest rates and Decamps, Gryglewicz, Morellec, and Villeneuve (2017) examine transitory shocks. Haushalter (2000), Rampini, Sufi, and Viswanathan (2013) and Doshi, Kumar, and Yerramilli (2015) empirically examine hedging activity in commodity markets.

More broadly, our quantitative work is related to the large literature on dynamic capital structure and investment, starting with Gomes (2001) and Hennessy and Whited (2005, 2007). More recent papers emphasizing risk management through cash holdings include Gamba and Triantis (2008), Riddick and Whited (2009), and Eisfeldt and Muir (2016), and especially Bhamra, Kuehn, and Strebulaev (2011) and Begenau and Salomao (2015) who examine financing decisions in the presence of aggregate risk, similar to us.

A growing literature in macroeconomics and finance examines empirically and theoretically the links between various measures of uncertainty and real activity. A non-exhaustive list of classic and recent papers documenting negative links between uncertainty and real activity at either the aggregate or the firm level includes Leahy and Whited (1996), Bloom, Bond, and Van Reenen (2007), Bloom (2009), Kim and Kung (2014), Ludvigson, Ma, and Ng (2015), and Alfaro, Bloom, and Lin (2016). More recently, a particular manifestation of uncertainty, namely policy uncertainty, has attracted interest, including the work of Pástor and Veronesi (2012, 2013), Kelly, Pástor, and Veronesi (2016), and Gulen and Ion (2016). In contrast to interest rate uncertainty, most of these manifestations of uncertainty cannot readily be hedged.

2 Motivation

In this section, we first outline our data and then present some motivational results. In particular, we document a strong negative link between measures of interest rate uncertainty and future aggregate economic activity. We use data from several sources starting in 1994 and ending in 2014.

2.1 Data

Interest Rate Uncertainty: Our primary measure of interest rate uncertainty is an implied volatility index extracted from one-month options written on 30-year Treasury futures (TIV henceforth), as constructed in Choi, Mueller, and Vedolin (2017). TIV is akin to the well-known VIX index which is calculated from one-month equity index options on the S&P500. For robustness, we alternatively use the MOVE index, the Bank of America-Merrill Lynch volatility index from Treasury options, realized volatility of a one-year constant maturity Treasury yield, and the interquartile range from survey forecasts of the three-month Treasury yield from the Philadelphia Federal Reserve.[2]

Previous literature has demonstrated a link between investment and a variety of manifestations of uncertainty. In order to isolate the effects of interest rate uncertainty from broader forms of macroeconomic or financial uncertainty not specific to interest rates, so as to gauge the impact of

[2] We refer to the online appendix for a detailed sensitivity analysis using different interest rate uncertainty proxies, sub sample analysis, as well as further empirical results.

interest rate uncertainty above and beyond policy, macroeconomic and other financial uncertainty, we run the following regression:

$$\text{TIV}_t = c + b \text{ other uncertainty}_t + e_t,$$

and use the residuals from this regression, $\hat{e}_t$, as a regressor. In order to avoid any look ahead-bias, we estimate residuals using an expanding window of 20 quarters. More specifically, we use 20 quarters worth of data to estimate the residual for quarter 21 and then continuously expand the window to estimate the next quarter residual.

Other uncertainty measures include the policy uncertainty index of Baker, Bloom, and Davis (2016) and the macroeconomic and financial uncertainty indices of Jurado, Ludvigson, and Ng (2015).[3] While these indices are ex-post measures of policy or macro uncertainty, our interest rate uncertainty index is forward-looking since it is based on option prices. To disentangle interest rate uncertainty from a forward-looking measure of macroeconomic uncertainty, we also orthogonalize TIV with respect to survey forecasts on future GDP available from the Philadelphia Federal Reserve.

Macroeconomic variables: We use standard macroeconomic variables such as GDP growth, the level of the federal funds rate, and the term spread, defined as the difference between the ten-year and three-month constant-maturity Treasury yields. To proxy for aggregate credit risk, we employ Moody's Baa-Aaa credit spread and the Gilchrist and Zakrajšek (2012) credit index which is calculated from a large cross-section of firm level corporate bonds traded in the secondary market.

Hedging variables: We start with a sample consisting of the largest 1,600 firms in Compustat.[4] We then augment this data set with hand-collected data on interest rate swap usage from EDGAR. Following Chernenko and Faulkender (2011), we use 10-K reports from the EDGAR database to determine the amount of floating rate long-term debt and the notional amounts and directions of interest rate swaps outstanding at the end of each fiscal year.[5] This allows us to calculate the net

[3] Baker, Bloom, and Davis (2016) construct an economic policy uncertainty index based on the frequency of news articles in 10 leading US newspapers. Jurado, Ludvigson, and Ng (2015) fit a factor model to 132 macro and 147 financial variables to generate forecasts thereof. The authors then assume that the volatilities of individual forecast errors follow a univariate stochastic volatility process, whose average becomes macroeconomic or financial uncertainty.

[4] We cut our sample at 1,600 firms as very small firms make little use of financial derivatives but rather adjust their interest rate risk exposure through credit lines with banks (see e.g., Vickery (2008)).

[5] We defer a detailed discussion of how we collect and filter the interest rate swap usage data to the online appendix.

floating swap amount as the pay-floating-receive-fixed notional amount minus the pay-fixed-receive-floating notional amount. The result is then divided by the total debt outstanding at the end of the fiscal year to get the net share of the firm's debt that is swapped to floating. This variable can take values between -1 (all debt is swapped to fixed) and 1 (all debt is swapped to floating). In what follows, this variable is referred to as *% swapped*. The absolute value of this variable (|*% swapped*|) measures the net notional amount of interest swaps outstanding as a percentage of the firm's total debt and indicates to which extent a firm engages in interest rate swaps. We also calculate the percentage of total debt that is floating both before (*initial % floating*) and after (*% floating*) consideration of the interest rate swap effects. These two variables take values between 0 and 1. We drop observations that do not provide enough information in their 10-K filings to determine the amount of floating rate debt or the notional amounts of outstanding interest rate swaps. Applying these different filters leaves us with 17,631 firm-year observations.

Firm-level determinants: We complete our data set with standard firm-specific information that we gather from Compustat and Capital IQ, and financial constraints measures based on the work of Whited and Wu (2006), Hoberg and Maksimovic (2015), and Hadlock and Pierce (2010).[6] Finally, we use credit default swap data from Markit and expected default probability (EPD) data from the Risk Management Institute at National University of Singapore as measures of financial distress. We collect the details in the appendix.

2.2 Interest rate uncertainty and economic activity

We begin our empirical analysis by investigating the relationship between interest rate uncertainty and real activity. As a preliminary exploration of our data, we plot in Figure 2 four-quarter changes in aggregate investment together with our proxy of interest rate uncertainty. The pattern emerging is that the co-movement between the two variables is strongly negative.

[insert Figure 2 here]

More formally, we now document the relationship between aggregate investment and interest rate

[6] We thank Gerard Hoberg and Vojislav Maksimovic for sharing their data with us.

uncertainty by means of predictive regressions using a one-year (four-quarter) horizon.[7] We use TIV along with a number of relevant forecasting variables to predict aggregate investment. More specifically, we run the following regression:

$$\Delta \mathrm{I}_{t+4} = \alpha + \sum_{i=1}^{p} \delta_i \Delta \mathrm{I}_{t-i} + \beta\, \mathrm{TIV}_t + \gamma' X_t + \epsilon_{t+4},$$

where $\Delta \mathrm{I}_{t+4}$ is one-year ahead changes in investment, TIV_t interest rate uncertainty, and X_t is a vector of controls which includes the term spread, federal funds rate, the Gilchrist and Zakrajšek (2012) credit spread, Moody's Baa-Aaa credit spread, VIX, and GDP growth.[8] Table 1 summarizes the results.

[insert Table 1 here]

Corroborating our earlier observation, we find the estimated coefficient of interest rate uncertainty, $\hat{\beta}$, to be negative and highly statistically significant. The coefficient is not only statistically significant but also economically meaningful. For example, for any one standard deviation change in interest rate uncertainty, there is on average a 0.365 standard deviation change in the growth rate of aggregate investment which translates into an average $25 billion movement. Interest rate uncertainty remains highly statistically significantly negative when we add other predictors known to affect investment, as documented in columns (2) to (5).

We next use residuals from regressing TIV onto alternative uncertainty indices to isolate the effects of interest rate uncertainty beyond broader manifestations of uncertainty. Columns (6) and (7) show that interest rate uncertainty is a significantly negative predictor of aggregate investment beyond broad policy uncertainty as measured by Baker, Bloom, and Davis (2016), while columns (8) and (9) document that this is not a mere reflection of overall uncertainty in financial markets, as measured by the financial uncertainty index proposed in Jurado, Ludvigson, and Ng (2015). The same observations hold when conditioning interest rate uncertainty on macroeconomic uncertainty (see columns (10) and

[7] To save space, we present results for a one year horizon only. Regression results for longer horizons are summarized in the online appendix and we find them to remain qualitatively the same. The online appendix also contains results where, instead of aggregate investment growth, we use investment rate. We find the results to remain qualitatively the same.

[8] The forecasting regression is estimated by ordinary least squares (OLS), with the lag length p of each specification determined by the Bayesian Information Criterion. The $MA(4)$ structure of the error term ϵ_{t+4} induced by overlapping observations is taken into account by computing standard errors according to Hodrick (1992).

(11)). Finally, we also use a residual from regressing interest rate uncertainty on GDP growth forecasts and find this residual to be highly statistically significant (columns (12) and (13)).

These results suggest that interest rate uncertainty is associated with a significant slowdown in aggregate real activity, above and beyond other manifestations of uncertainty and business cycle predictors. Several explanations are potentially consistent with this pattern. It is consistent with real options effects, for example, as firms may delay exercising investment options in the face of elevated uncertainty when investment is only partially reversible. On the other hand, it may reflect uncertainty about interest rate payments associated with debt financed investment expenditures. As the latter cash flow channel can be hedged in interest rate swap markets, we next report some summary statistics on firms' hedging activity in the fixed income derivatives market, before dissecting competing explanations at the firm level.

2.3 Interest rate risk management summary statistics

We first report and describe simple summary statistics regarding swap usage in our data set in Table 2. In our sample, 63% of all firms use swaps. For the average firm-year, 37.4% of the outstanding debt has a floating interest rate exposure. The average swap is equivalent to 6.9% of the firm's debt, but since some firms swap to floating (fair value swaps) while others swap to fixed (cash flow swaps), a net average of 1.7% of the firm-year's debt is swapped to a floating interest rate exposure, leaving the average firm-year with 35.8% of floating rate debt. These numbers echo the findings in Chernenko and Faulkender (2011) who document that firms tend to be fixed rate payers.

[insert Table 2 here]

Figure 3 illustrates average cash flow and fair value swap notionals over time for the companies in our sample. We observe that in times of elevated interest rate uncertainty, firms' usage of cash flow swaps rises in proportion. In other words, when TIV is high, firms increasingly attempt to swap floating rate payments for fixed rate payments, and vice versa.

[insert Figure 3 here]

3 Model

To interpret our empirical findings, we now develop a dynamic model that allows to trace aggregate effects of interest rate uncertainty down to firm-level corporate investment and financing, and considers firms' option to hedge interest rate related risks in the swap market. The purpose of the model is to generate testable predictions on the cross-sectional and time-series determinants of hedging and the real effects of interest rate uncertainty, as well as to provide a benchmark against which empirical findings can be evaluated by means of counterfactuals.

Our setting builds on recent dynamic models of corporate investment and financing with costly external finance (see e.g., Hennessy and Whited (2007)) and adds a fairly realistic account of the interest rate environment. This amounts to specifying interest rate dynamics exhibiting stochastic volatility, aggregate macro shocks and volatility that drive long-term yields, as well accounting for the fixed versus floating rate mix in firms' debt structures.[9] Finally, firms have an incentive to engage in risk management by transferring funds to states in which those allow them to avoid the costs of external finance. In our model, one period interest rate swaps provide an instrument to hedge interest rate risks.

We start with a description of the model, then outline the calibration procedure, and finally provide some empirical predictions regarding the determinants of interest rate risk exposure, management, and its effects on real outcomes.

3.1 Setup

We model a cross-section of firms i in the presence of interest rate and aggregate and firm specific profitability risks. These risks give rise to stochastic investment opportunities and funding needs that firms may attempt to hedge because of financial frictions. The composition of the cross-section of firms changes over time, as firms exit upon default and new firms enter if prospects are sufficiently good.

Interest Rate Risk and Uncertainty We distinguish between interest rate risk, namely stochastic changes in the risk-free short-term interest rate, r_t, and interest rate uncertainty, that is, stochastic

[9] To make the model as parsimonious as possible, we model real interest rates while in the data, we focus on interest rate swaps and interest rate uncertainty on nominal interest rates. Empirically, we find that neither measures of expected inflation nor inflation uncertainty have a significant effect on our results.

movements in its conditional volatility σ_{rt}. The interest rate follows a mean-reverting process with stochastic volatility

$$r_{t+1} = (1 - \rho_r)\bar{r} + \rho_r r_t + \sigma_{rt}\eta_{t+1}, \tag{1}$$

with $\eta_t \sim \mathcal{N}(0,1)$, persistence $0 < \rho_r < 1$, and conditional volatility σ_{rt}. The conditional variance σ^2_{rt} follows the process

$$\sigma^2_{rt+1} = (1 - \rho_{\sigma r})\bar{\sigma}^2_r + \rho_{\sigma r}\sigma^2_{rt} + \sigma_{rt}\sigma_w w_{t+1}, \tag{2}$$

where $w_t \sim \mathcal{N}(0,1)$ and is independent from η_t. Occasionally, we will refer to overall interest rate risks, subsuming both interest rate risk and uncertainty.

To account for movements in macroeconomic conditions that may affect real activity, as well as long term yields, we model aggregate profitability shocks as

$$x_{t+1} = \rho_x x_t + \sigma_{xt}\zeta_{t+1}, \tag{3}$$

where σ_{xt} denotes their conditional volatility. For tractability, we assume that shocks to profitability are perfectly negatively correlated with shocks to its conditional variance (see e.g., Bhamra, Kuehn, and Strebulaev (2010) or Kuehn and Schmid (2014)). This is a simple way to capture the empirical evidence that aggregate volatility is sharply countercyclical.[10] Accordingly, the conditional variance σ^2_{xt} satisfies

$$\sigma^2_{xt+1} = (1 - \rho_{\sigma x})\bar{\sigma}^2_x + \rho_{\sigma x}\sigma^2_{xt} - \sigma_{xt}\sigma_\zeta\zeta_{t+1}. \tag{4}$$

Following Backus, Foresi, and Telmer (2001), we directly specify the stochastic discount factor that governs the pricing of aggregate interest rate and aggregate profitability risks. The stochastic discount factor is given by

$$\begin{aligned} \log M_{t+1} \quad = \quad & -r_t - \left(\frac{1}{2}\lambda^2_r + \frac{1}{2}\lambda^2_\sigma\sigma^2_w\right)\sigma^2_{rt} - \frac{1}{2}(\gamma_x - \gamma_\sigma\sigma_\zeta)\sigma^2_{xt} - \lambda_r\sigma_{rt}\eta_{t+1} \\ & -\lambda_\sigma\sigma_{rt}\sigma_w w_{t+1} - (\gamma_x - \gamma_\sigma\sigma_\zeta)\sigma_{xt}\zeta_{t+1}, \end{aligned} \tag{5}$$

where λ_r is the price of interest rate risk, λ_σ is the price of interest rate uncertainty, γ_x is the price of aggregate profitability risk and γ_σ the price of aggregate volatility risk.[11] This specification gives rise

[10] The correlation between the VIX, a popular measure of volatility, and output growth is about -0.37, in our sample.

[11] Note that the prices of aggregate profitability and volatility risk are not separately identified, given our assumption of perfect negative correlation between the respective innovations.

to discount rate risk through stochastic interest rates, and, by no arbitrage, to a flexible, three-factor affine term structure model.

Firm Investment and Financing Firm i makes optimal investment, financing and hedging decisions in the presence of aggregate interest rate and profitability risks, as well as firm-specific profitability shocks, denoted z_{it}. We assume that firm i's profitability shock z_{it} follows the mean-reverting process

$$z_{it+1} = \rho_z z_{it} + \sigma_z \xi_{it+1}, \tag{6}$$

with $E[\xi_{it}\xi_{jt}] = 0$, whenever $i \neq j$. Persistent firm level shocks give rise to a non-degenerate cross-sectional distribution of firms at any point in time. This distribution changes over time for two reasons. First, firms adjust their policies in response to shocks, and second, firms default and new firms enter. We assume that before entry, potential entrants draw a realization of their profitability from the unconditional distribution of z_{it}. Given that signal, they make an entry decision, and upon entry, purchase an initial capital stock k_{it}. We describe the endogenous entry process in more detail below.

Once the capital stock is in place, incumbent firm i generates per-period, after tax profits π_{it} given by

$$\pi_{it} = (1-\tau)(\exp(x_t + z_{it})k_{it}^{\alpha} - f), \tag{7}$$

where τ denotes the corporate tax rate, $0 < \alpha < 1$ is the capital share in production, and f is a fixed cost incurred in the production process. A capital share less than unity captures decreasing returns to scale.

Firms scale their operations by adjusting the level of productive capacity k_{it} through intermittent investment, i_{it}, which is linked to the capital stock by the standard accumulation rule

$$k_{it+1} = (1-\delta)k_{it} + i_{it}, \tag{8}$$

where $\delta > 0$ denotes the depreciation rate of capital. In our baseline case, we accommodate that firms posses real investment options in that investment is irreversible, that is,

$$i_{it} \geq 0. \tag{9}$$

In the U.S. tax code, interest payments on corporate debt are tax deductible. Firms therefore have an incentive to use both equity and debt to finance expenditures. Issuing equity entails transaction costs, as detailed below. To account for key patterns regarding firms' debt structures in the data, we assume that debt comes in two forms, namely long-term corporate bonds that we model as defaultable console bonds B_{it} with fixed coupons, as well as short-term bank debt that comes in the form of defaultable one-period loans b_{it} with a floating rate. Since firms can default, that rate entails a default premium δ_{it} over the risk-free rate, so that the net floating rate is given by $r_t + \delta_{it}$. For tractability, we assume that firms issue long-term fixed rate debt at the entry stage only, to finance the initial capital stock. Therefore, in our model, after entry firms can only get new exposure to fixed rates by borrowing floating rate, and subsequently swapping[12] . For the remainder of their lifetimes, they therefore face fixed, firm-specific, coupon commitments d_i in every period. We determine the coupons d_i and the premiums δ_{it} endogenously below.

Risk Management and Swaps In the model, stochastic interest rates impose risks on firms through different channels. Clearly, there is *financing risk*, as movements in the short-term interest rate directly affect interest payments on bank debt. Then, there is *valuation risk* as short rates impact valuations through the stochastic discount factor. In this context, firms may find it beneficial to partially hedge their exposure to interest rate risk by means of interest rate swaps.

We assume banks offer contracts that allow to exchange floating rate payments for a fixed swap rate one period ahead, or vice versa. We assume that entering a swap contract entails a fixed cost ψ, capturing transactions costs associated with trading swaps in over-the-counter (OTC) markets, such as posting costly collateral.[13] We denote the notional amount of swap contracts purchased at time t by s_{it}. Whenever $s_{it} > 0$, the firm is a net floating rate payer, while $s_{it} < 0$ indicates a net fixed rate payer. The swap rate equals the current short-term interest rate plus a swap spread sp_t, which is

[12] This assumption, albeit clearly stylized, still allows us to rationalize a variety of empirical patterns regarding corporate debt structures, as detailed below, while circumventing convergence (see, e.g., Chatterjee and Eyigungor (2012)), time-inconsistency and debt dilution (see, e.g., Gomes, Jermann, and Schmid (2016)), or multiple equilibria (see, e.g., Crouzet (2016)) problems associated with defaultable long-term debt modeling.

[13] Historically, interest rate derivatives were traded in OTC markets and hedging-associated costs mainly consisted of posting collateral as well as trading and execution fees. Since the implementation of the Dodd-Frank Act, Deloitte (2014) estimates a further increase in hedging-related costs both for centrally cleared and non-cleared products.

determined so as to equalize expected payments to both ends of the swap. In other words, we have[14]

$$r_t + sp_t = E_t\left[M_{t+1} r_{t+1}\right]. \tag{10}$$

Swaps do not consume resources ex ante, apart from fixed costs, but either free up or consume resources ex post, depending on the realization of the short rate. For floating rate payers, entering into a swap arrangement frees up resources when the short-term interest rate falls, so that the contract effectively transfers resources from future high interest rate states to low interest rate states, while it consumes resources for fixed rate payers, and vice versa. Thus, while swaps allow to transfer resources in a state-contingent manner, they entail fixed costs.

Valuation The equity value of the firm, V_{it}, is the present value of all future equity distributions. We assume that equity holders will choose to close the firm and default on their debt repayments if the prospects for the firm are sufficiently bad, that is, whenever V_{it} reaches zero.

Equity payout e_{it}, investment and financing decisions must satisfy the budget constraint

$$\begin{aligned} e_{it} &= \pi_{it} - i_{it} - (1-\tau)d_i + b_{it} - \left(1 + (1-\tau)(r_{t-1} + \delta_{it-1})\right) b_{it-1} \\ &\quad + s_{it-1}(r_{t-1} + sp_{t-1} - r_t) - \psi \mathbb{I}_{\{s_{it} \neq 0\}}. \end{aligned} \tag{11}$$

The budget constraint recognizes the tax deductibility of the coupon payments on long-term corporate bonds and on floating rate bank debt. Finally, the last term captures payments arising from the swap position contracted last period, including the fixed cost associated with entering a new swap contract, as emphasized by the indicator function $\mathbb{I}$.

It is convenient to define a firm's net worth, the resources available for investment, financing and risk management at the beginning of period t, after the realization of the shocks, as

$$w_{it} = \pi_{it} - (1-\tau)d_i - \left(1 + (1-\tau)(r_{t-1} + \delta_{it-1})\right) b_{it-1} + s_{it-1}(r_{t-1} + sp_{t-1} - r_t). \tag{12}$$

Intuitively, the lower a firm's net worth the more it needs to rely on external funds to finance investment and swap positions. In other words, net worth measures a firm's financial slack, and the lower net worth, the more financially constrained it tends to be.

[14] We assume that promised swap payments have priority in bankruptcy, implying that even though firms' default is a possibility, they will always fully honor payments promised in the swap contract, as discussed in Bolton and Oehmke (2015). As a consequence, the swap pricing equation does not reflect default probabilities.

We interpret negative payouts as capital inflows into the firm in the form of a seasoned equity offering that entails underwriting costs. We consider fixed and proportional costs, which we denote by λ_0 and λ_1, following Gomes (2001). Formally, we set

$$\lambda(e_{it}) = (\lambda_0 + \lambda_1 |e_{it}|)\mathbb{I}_{\{e_{it}<0\}}. \tag{13}$$

Distributions to shareholders, denoted by d_{it}, are then given as equity payout net of issuance costs,

$$d_{it} = e_{it} - \lambda(e_{it}). \tag{14}$$

We now characterize the problem facing equity holders, taking payments to debt holders as given. The value of these payments will be determined endogenously below. Shareholders jointly choose investment, i_{it}, bank debt, b_{it}, and swap positions s_{it} to maximize the equity value of each firm. The equity value is the solution to the dynamic program

$$V_{it} = \max\left\{0, \max_{i_{it},b_{it},s_{it}} \{d_{it} + E_t\left[M_{t+1}V_{it+1}\right]\}\right\}. \tag{15}$$

The first maximum captures the possibility of default at the beginning of the current period, in which case shareholders will get nothing. Implicit in this formulation is that the firm simultaneously defaults on bank debt and corporate bonds.

We assume that in default, the total pool of creditors recovers a fraction of the firm's current assets and profits net of liquidation costs and any payments promised from swap contracts, as payments arising from the swap are senior in default. Formally, then, the default payoff is equal to

$$R_{it} = (1-\xi)(\pi_{it} + k_{it}) + s_{it-1}(r_{t-1} + sp_{t-1} - r_t), \tag{16}$$

where ξ measures the proportional loss in default.[15] We then split the total recovery according to their respective book values[16] into short-term debt recovery R^s_{it} and long-term debt recovery R^l_{it} so that the payments on bank debt must satisfy the Euler condition

$$b_{it} = E_t\left[M_{t+1}\left((1-\mathbb{I}_{\{V_{it+1}=0\}})(1+r_t+\delta_{it})b_{it}\right) + \mathbb{I}_{\{V_{it+1}=0)\}}R^s_{i,t+1}\right)\right]. \tag{17}$$

[15] Note that the requirement that recoveries are non-negative implicitly imposes limits on the amount of swap contracts the firm can enter. These limits are not binding in our simulations.

[16] We identify the book value of long-term debt with its market value at entry.

Similarly, the market value of long-term debt B_{it} must satisfy the recursion

$$B_{it} = E_t \left[M_{t+1} \left((1 - \mathbb{I}_{\{V_{it+1}=0\}})(d_i + B_{it+1}) + \mathbb{I}_{\{V_{it+1}=0)\}} R^l_{it+1} \right) \right]. \tag{18}$$

Entry Depending on aggregate and firm level conditions, a varying number of firms finds it optimal to default on their debt obligations according to (15) , and exit the economy after liquidation. In order to allow for a long-run stationary economy, we complete the model with a specification of entry. We follow Gomes and Schmid (2016) in assuming that every period, there is a unit mass of potential entrant firms drawing an entry cost χ_{it} in an iid fashion from a uniform distribution defined on the support $[0, X]$. At the same time, they draw a signal about the next period realization of their idiosyncratic profitability shock z_{it+1}. Conditional on that signal, firms enter whenever their maximum expected firm value[17] exceeds the entry cost, that is, whenever

$$\chi_{it} \leq \max \left\{ 0, \max_{k_{it+1}, d_i} \left\{ E_t \left[M_{t+1}(V_{it+1} + B_{it+1}) \right] \right\} \right\}. \tag{19}$$

The entry condition makes clear that firms' initial capital stocks, that it, their scale, as well as their long-term, fixed rate debt, through the choice of d_i, depend on both aggregate conditions, and firm-specific conditions such as the signal about z_{it+1}, at time t, embodied in valuations. Our specification thus gives rise to endogenous variation in firm size and debt structure in the time-series and the cross-section.

Discussion The previous paragraphs introduce a dynamic model of corporate investment, financing and interest rate risk management in the presence of aggregate risk, interest rate uncertainty, and financial frictions. The possibility of default and the associated deadweight costs of liquidation, as well as equity issuance costs, give scope to value-enhancing hedging of aggregate interest rate risk and uncertainty by means of swaps. We now briefly discuss the basic mechanisms driving corporate policies and the dynamics of the aggregate cross-section of firms.

The entry condition (19) determines the evolution of the aggregate scale of the economy. Lower interest rates and lower uncertainty forecast high valuations, low default, and easier access to credit markets, with ensuing entry and investment waves. As a consequence, long expansions lead to the entry of larger firms on average, while the marginal firm entering in downturns is relatively smaller.

[17] We assume that firms enter without bank debt and with zero swap positions.

Variation in the scale of new entrants gives rise to a realistic average debt structure in the cross-section. With more collateral and more stable cash flows, larger firms find it easier to exploit the tax advantage of long-term, fixed rate corporate bonds and can manage their liquidity needs more conservatively relying less on bank debt. This is consistent with the empirical evidence that firms issue long-term debt procyclically (see, e.g., Lopez-Salido, Stein, and Zakrajšek (2017)). Smaller firms, on the other hand, have less collateral, higher Tobin's Q, and more volatile cash flows. Consequently, risk management is more valuable to them and they need to rely more on bank debt to manage their liquidity needs. In the model, therefore, smaller firms' debt structure is tilted towards floating rate, bank debt.

What determines the amount of swap usage in the model? First of all, fixed costs make it relatively more costly for small firms to enter into a swap contract. All else equal, larger firms are thus more likely to use interest rate derivatives to hedge their exposure. Among swap users, however, smaller firms and firms with higher Tobin's Q make use of swap contracts more extensively. Given fixed costs of production, decreasing returns to scale, and a debt structure dominated by floating rate debt, they have higher exposure to interest rate risks and hedging it is more valuable to them.

What determines the direction of swap usage in the model? Intuitively, firms tend to be net floating rate payers if their liquidity needs are concentrated in low interest rate states, as the swap contract frees up resources ex post when interest rates fall. Liquidity needs arise both in states in which default and equity issuance is more likely. Smaller firms have more floating rate debt so adverse movements in interest rates push them closer to default as they have to refinance at a higher rate. They thus benefit from transferring resources to future high interest rate states, so that we expect them to be net fixed rate payers. This is the *financing* channel. In contrast, falling interest rates increase valuations through the discount rate and thus foster investment, which tends to push firms to the equity issuance margin, so that they benefit from transferring funds to low interest rate states. All firms with investment opportunities benefit from this *valuation* channel. The aggregate swap position in the model depends on the relative strength of these forces and is related to the firm size distribution. To gauge these magnitudes, we now turn to a calibration.

To keep our model tractable, our setup abstracts from two channels that likely affect firms' interest rate and risk management practices more broadly. First, in practice, firms can change their exposure to fixed rates after entry not just by using swaps, but by dynamically issuing new long-term debt that tends to come with fixed coupons. Second, firms hold significant amounts of cash on their balance sheets that can serve as a buffer in states with high liquidity needs. While our modeling choices are guided by computational concerns, we expect our main mechanisms to remain qualitatively and quantitatively relevant in richer settings with cash and dynamic rebalancing of firms' debt structures.

Regarding rebalancing, both in our model and in the data it is the smaller firms that tend to swap to fixed rate, so that they might potentially have an interest in getting fixed rate exposure by issuing long-term debt directly. However, smaller firms also tend to have higher Tobin's Q and thus ample investment options as well, exercising which will be hindered by debt overhang problems stemming from long-term debt, which is costly. Given the considerable size of debt overhang costs estimated in the literature (see e.g. Hennessy (2004) or Kurtzman and Zeke (2017)), one rationale why smaller firms' debt structure tends to be tilted towards bank debt may be that it is cheaper for them to get fixed rate exposure by borrowing floating rate and swapping, thereby avoiding debt overhang costs going forward. Debt overhang is less of a concern for larger, mature firms, but additional fixed rate exposure would tend to exacerbate their swapping to floating rate. Overall, therefore, we expect our model implications to be robust to that additional degree of realism.

In the model smaller firms' preference for fixed rate exposure is driven by the occurrence of liquidity needs. Clearly, holding cash constitutes an alternative form of liquidity provision. However, given the considerable opportunity and agency costs of cash holdings estimated in the literature (see e.g. Nikolov and Whited (2014)), managing interest rate risks by means of swaps appears preferential as it allows firms to tailor their risk management strategies precisely to the occurrence of states with high liquidity needs. Indeed, similar to Nikolov, Schmid, and Steri (2017), swaps provide an instrument for *contingent liquidity* management, in that they allow firms to transfer resources to specific states only, while cash provides *non-contingent liquidity* in that it transfers resources across all future states symmetrically, including those with low liquidity needs where the marginal value of net worth is low. Relying on cash only rather than swaps for risk management purposes would, therefore, likely push firms to favor costly equity over tax-preferred debt instruments as sources of external financing, and hinder a more effective allocation of resources across states, with detrimental effects on firm value and investment.

3.2 Calibration

The model is calibrated at an annual frequency. We summarize our parameter choices in Table 3, Panel A. Our benchmark model requires that we specify parameter values for financing costs, for technology, and for the specification of the stochastic discount factor which includes the stochastic process for the short rate. We pick a subset of them to match moments pertinent to our analysis, and compute these empirical targets over the period from 1994 to 2014, consistent with our data sample on swap usage. Our choice of the remaining parameters follows the literature.

[insert Table 3 here]

For the purpose of our annual calibration, we identify the short rate with the one-year U.S. Treasury rate, and choose the short rate parameters to match its mean, its autocorrelation, as well as movements in its conditional volatility. In practice, we achieve this by fitting a GARCH process to our target short rate. Our calibration of the aggregate profitability parameters follows the literature, and is consistent with the estimates in Cooley and Prescott (1995) and Kung (2016). While it is well known that the risk price parameters are difficult to pin down empirically (see e.g., Bikbov and Chernov (2009) or Collin-Dufresne, Goldstein, and Jones (2009)) our parameter choice is designed to generate term spreads on U.S. Treasuries as well as credit spreads on short- and long-term corporate bonds, along with volatilities of long term yields, in line with the data. The latter ensures that the model generates a realistic amount of long-term interest rate uncertainty. Matching a positive term spread and realistic term spread volatility requires both λ_r and λ_σ to be negative. Compensation for systematic default risk empirically makes up for a substantial component of credit spreads, as discussed in the literature on the "credit spread puzzle" (see e.g. Chen, Collin-Dufresne, and Goldstein (2009), Chen (2010), and Bhamra, Kuehn, and Strebulaev (2010)), requiring the price of aggregate profitability risk γ_x to be positive. In our setup with perfectly negatively correlated aggregate profitability and volatility shocks, only the difference between their risk prices is identified, which we set to 2.

The literature provides good guidance on the choice of the firm-level technological parameters (ρ_z, σ_z, α, f, δ, and τ). We set the capital share α of production equal to 0.65 and calibrate f to 0.03, similar to Gomes (2001). This choice is consistent with observed levels of firm level profitability, as well as market-to-book ratios.[18] At the firm level, we calibrate the volatility σ_z and persistence ρ_z of the idiosyncratic profitability process to match the cross-sectional dispersion in leverage and profitability. We set the effective corporate tax rate τ to 14%, consistent with the evidence in van Binsbergen, Graham, and Yang (2010), allowing us to rationalize moderate levels of leverage. The choice of δ is standard and allows to match realistic investment rates.

The choice of financing parameters quantitatively determines the magnitude of financial frictions that firms face, and thus their incentives to engage in risk management. Issuance cost parameters in equity markets are set to be consistent with the data on new issuances. In general, our parameter choices are similar to the estimation results in Hennessy and Whited (2005, 2007). Regarding bankruptcy costs, Andrade and Kaplan (1998) report default costs of about 10% to 25% of asset value. Finally, we calibrate the swap issuance cost ψ to an industry average that we obtained by contacting one of the largest swap dealers. While perhaps somewhat anecdotal, the model implications are robust to modest variations of that choice.

We solve the model using discrete state space dynamic programming methods. A description of the computational procedure can be found in Section 2 of the online appendix.

Quantitative Implications Our quantitative analysis is based on simulations. To that end, we create artificial panels comparable to our data sample.[19] Table 3, Panel B, reports basic unconditional moments generated by the model along with their empirical counterparts and shows that they are broadly consistent with the data, as targeted by our parameter choices. In the model, firms' hedging motives reflect the possibility of costly default and equity issuance. Regarding default, the model gives rise to realistic credit spreads, and average market leverage and dispersion. In spite of substantial tax benefits to debt, with aggregate risk, firms pick moderate leverage to preserve borrowing capacity in bad times. Regarding access to costly external equity finance, the model generates infrequent, but rather sizable equity issuances broadly in line with the data.

Critically, the model is consistent with basic facts about corporate swap usage. First of all, as

[18] We note that our sample contains the technology boom of the late nineties, with inflated valuations. During our sample period, market-to-book ratios are therefore unusually high.

[19] We thus simulate 1,600 firms over a period of 20 years. To avoid dependence on arbitrary initial conditions, we simulate 500 years, but drop the first 480 years when computing model statistics. We repeat that procedure 50 times.

in the data, a significant fraction of firms does not use swaps at all. Within the context of the model, this is rationalized by the fixed cost of entering into a swap contract, ψ, on the one hand. On the other hand, even in the absence of swap issuance costs, some firms choose to refrain from using swaps, as the financial commitments for fixed rate payers when interest rates suddenly fall push them closer to issuing costly equity, and default, and vice versa. Moreover, while not explicitly targeted, given realistic interest rate risk exposure and risk management incentives, the model also replicates reasonably well the overall amount and direction of swap usage. Specifically, firms are fixed rate payers on average, as in the data.

3.3 Empirical Implications

We now use our calibration to distill the intuitive discussion of the model mechanisms into testable predictions. Empirically testing these predictions in Section 4 provides the main external validation of our model. We first verify that at the aggregate level, our simulated panels rationalize the predictive power of interest rate uncertainty for economic activity documented in Section 2, and then use them to generate empirical predictions on the cross-sectional and time-series determinants and effects of interest rate risk management on real outcomes, as well as counterfactuals.

Aggregate Implications Our investigation was motivated by the empirical finding, documented in Table 1, that adverse movements in interest rate uncertainty predict significant slowdowns in aggregate investment growth, among others. Table 4, shows that for the benchmark model, aggregating firm-level data in the simulations, gives rise to qualitatively similar patterns, with magnitudes that are within the range or their empirical counterparts. Indeed, in our benchmark model, model (1) in the table, interest rate uncertainty predicts aggregate investment growth significantly negatively in simulated regressions. This finding qualitatively survives, albeit quantitatively slightly weakened, in model specifications in which we abstract from additional sources of aggregate volatility driving movements in investment, such as countercyclical volatility in aggregate profitability (model (2)), and aggregate profitability shocks altogether (model (3)). This corroborates the empirical observation in Table 1 that interest rate uncertainty is a significant source of movements in real activity, beyond standard sources and predictors of aggregate volatility.

[insert Table 4 here]

Figure 4 further inspects the effects of the different sources of aggregate volatility in our baseline model, via impulse response functions. To compute those, we simulate 500 periods from our model, keeping all the aggregate shocks at their mean, and then hit the economy with a one standard deviation negative aggregate profitability shock, a positive interest rate shock, and a positive interest rate volatility shock, respectively, while keeping the other aggregate shocks constant. To account for movements in firms' idiosyncratic profitability shocks, we repeat this procedure one hundred times, and average the responses. To trace out the effects of key real and financial variables, we focus on the responses of aggregate capital, the long-term debt share in firms' debt structures, as well as the average absolute swap position, and compare those in our benchmark model with those in a model specification with fully reversible investment, as well as one without debt financing.

[insert Figure 4 here]

Capital falls on impact when profitability is reduced, and when interest rates and interest rate volatility rise, in all model specifications. The effects of adverse interest rate uncertainty shocks on investment are muted in the alternative specifications, and especially so when investment is equity financed only. Rises in interest rate uncertainty also come with increases in the aggregate swap position in the model, and firms increasingly swap to fixed rate, consistent with the empirical evidence in Figure 3. Notably, the aggregate swap position falls when interest rates rise, and profitability falls, reflecting firms' reduced resources to engage in risk management. In response to an adverse interest rate uncertainty shocks, firms' tend to reduce their exposure to short-term, floating rate debt, leading to a rise in the long-term debt share, similar to the response to a negative aggregate profitability shock, when reduced resources lead to a reduction in short-term debt. The long-term debt share falls, however, in response to interest rate rises when a reduction in short-term debt due to higher financing costs is compensated by a fall in long-term debt values.

Cross-sectional Implications Ultimately, the aggregate effects of interest rate volatility on investment in our model reflect corporate policies in response to movements in interest rate uncertainty across the firm distribution. Notably, firms may find it optimal to hedge interest rate uncertainty in the swap market, and these risk management practices may affect real outcomes. We now use simulated data to provide testable predictions on firm-level investment and risk management policies in the presence of interest rate uncertainty.

Table 5 presents empirical predictions on corporate swap usage at the cross-sectional level. Panels A and B report unconditional univariate sorts of percentage of debt swapped along various firm characteristics, illustrating both swap direction and overall position.

[insert Table 5 here]

Size emerges as an important determinant of firms' hedging policies. Panel A predicts that, conditional on using swaps, smaller firms tend to be fixed rate payers. A similar prediction holds regarding firms with low net worth, high Tobin's Q and mostly short-term debt. Smaller firms tend to have more short-term, floating rate debt, so that their liquidity needs are concentrated in states when sudden raises in interest rates increase their funding needs. Engaging in a pay fixed receive floating rate swap frees up ex post resources in precisely these states. Notice that since we leave the financial intermediaries serving as counterparties unmodeled, the swap market does not clear in our setting and hence positions are not symmetric across firm bins.

Regarding absolute swap positions, the model predicts that smaller firms and firms with low net worth tend to hedge more, as shown in Panel B. It is interesting to note, however, that even after hedging, these firms' exposure remains elevated, as indicated by their relatively higher post-hedging cash flow interest rate betas and cash flow volatilities in Panel C. In the model, therefore, financial constraints prevent smaller firms from sufficiently reducing their exposure through the swap market.

Table 6 collects model predictions regarding the effects of interest rate uncertainty and hedging on real outcomes, in the form of panel regressions of future investment on relevant variables, as well as standard controls, in simulations. These predictions dissect the origins of the aggregate effects of interest rate uncertainty further at the firm level.

The first regression confirms that rises in interest rate uncertainty are associated with future declines in corporate investment at the firm-level. The next specifications provide further predictions along with some indications of the underlying model mechanisms. First, the effects of interest rate uncertainty are less pronounced for larger firms and firms with higher net worth. This pattern is consistent both with environments in which firms delay exercising investment options because of irreversibility (the classic real options effect) or with smaller firms' debt funding leaving them more burdened by floating rate payments (a cash flow effect). The negative interaction effect of interest rate uncertainty with leverage suggests that the cash flow effect is a relevant mechanism underlying the predictions. This relevance is corroborated by the prediction that hedging interest rate uncertainty in the swap market alleviates its effect on future investment.

[insert Table 6 here]

Counterfactuals Our empirical predictions in Table 6 suggest a relevant role for cash flow effects stemming from exposure to movements in floating rates on bank debt driving real effects of interest rate uncertainty. We next use simulated data as a laboratory to further disentangle the relevance of real options and cash flow effects underlying our predictions through counterfactual analysis. In particular, we present results from panel regressions of one-year ahead firm level investment on interest rate uncertainty, and controls, akin to those in Table 6, as well as relevant moments, in data simulated from various specifications nested in our benchmark model. The estimated coefficients allow us to gauge the real impact of interest rate uncertainty across various environments.

Table 7 reports the results. The first columns confront the benchmark model (i) with (ii) a model with fully reversible investment, thus lacking a real options channel, and (iii) a model in which firms are exclusively financed by costly equity[20] . We find that the negative effects of interest rate uncertainty on investment are barely alleviated when investment becomes reversible, suggesting that the effect of the real options channel is quantitatively weak. Indeed, firms exploit the additional flexibility by levering up more, which is accompanied by a modest increase in swap positions, leaving the frequency of equity issuance only slightly affected. However, the adverse effects of interest rate uncertainty are substantially weakened when firms use equity only to fund investment, as in (iii). We note that even in the latter case, elevated discount rate variation leads firms to cut back on investment, because equity financing is costly. Similarly, we observe that even absent debt financing, firms engage in interest rate risk management, albeit at a more modest scale, as firms benefit from additional resources to fund investment opportunities when interest rates fall. Accordingly, in untabulated results, we find that firms are on average net floating rate payers in this scenario. Together, these results suggest that the strength of the real option effect is quite modest in our setup, and reinforce the relevance of cash flow risks in shaping the link between interest rate uncertainty and investment, in the context of the model.

[20] In the online appendix, we provide further sensitivity regarding financing and investment frictions.

[insert Table 7 here]

We next consider the effectiveness and determinants of hedging these cash flow risks. In model specification (iv), we remove firms' access to swaps as a risk management tool, which amplifies the effects of interest rate uncertainty on real activity, corroborating the notion that the impact of uncertainty depends on firms' liquidity positions and hedging activity. In fact, the quantitative effect is quite substantial in that firms' investment is more than fifty percent more sensitive to fluctuations in interest rate uncertainty in the absence of hedging. This amplification is accompanied by a slight increase in the frequency of equity issuances, which is not entirely offset by the reduction in leverage.

The next entry in Table 7 sheds more light on the underlying mechanisms. In (v), we simulate a version of the benchmark model, but halve the volatility of idiosyncratic profitability shocks. Intriguingly, a reduction in idiosyncratic risk comes with an average swap position still substantially higher than in the benchmark specification. This observation emphasizes that as much as swap usage can free up resources ex post, adverse movements in interest rates (depending on the swap position) can create commitments and thus consume resources ex post. Such ex post commitments can specifically burden financially constrained firms when accompanied with adverse profitability shocks, as these may force them to cover these liquidity shortfalls by tapping costly external finance. In this sense, risk management by means of swaps can be risky for firms, especially when financially constrained. Accordingly, they are less reluctant to hedge when idiosyncratic profitability risks are reduced. Given lower risk to begin with and enhanced risk management, firms' average investment rate is substantially higher.

Finally, the last entry in the table allows to gauge quantitatively the marginal importance of time-varying volatility by fixing interest rate uncertainty at its mean. Indeed, relative to the benchmark specification, the average swap position drops, financial leverage rises, and the average investment rate rises as well. The quantitative effect on hedging is somewhat modest, however, in that in line with the observation above there is now less scope for hedging, but at the same time, it is *safer* to hedge. This corroborates the notion that hedging through swaps entails risk. Clearly, the regression coefficient on interest rate uncertainty is no longer meaningful in this case.

4 Empirical Evidence

Our model provides testable predictions regarding corporate investment and risk management in the presence of interest rate uncertainty, and their interactions in the cross-section. In this section, we test these predictions using panel regressions in our data set and present further supporting evidence.

4.1 Interest-rate uncertainty and firm-level investment

We first document a number of stylized facts regarding the link between interest rate uncertainty and corporate policies at the firm level, in line with our theoretical predictions.

Model Tests Table 8 reports predictive regressions from one-year ahead firm level investment on TIV and other firm level controls.[21] In line with the aggregate results, and our theoretical predictions in Table 6, we find that higher interest rate uncertainty lowers firm level investment. This effect is significant even when we control for a host of other variables, such as investment opportunities through Tobin's Q.

[insert Table 8 here]

Rather than by a decline in investment opportunities, therefore, the highly significant negative coefficients on leverage and size suggest an important role for financing constraints and financing in the transmission from interest rate uncertainty to corporate policies. The remaining columns in Table 8 explore this link further. We report regressions of predictive regressions of investment on TIV and TIV interacted with a host of other constraint measures.

To measure financial constraints, we use the Whited and Wu (2006), Hadlock and Pierce (2010), and Hoberg and Maksimovic (2015) indices, firm size, and net worth, and we include those along with their interaction terms with interest rate uncertainty in the regressions. The estimated coefficients indicate that in most cases (WW index, HP index, and HM index) financially constrained firms cut future investment more heavily compared to unconstrained firms. Similarly, we find that smaller firms and firms with lower net worth, i.e., more constrained firms, also decrease future investments when interest rate uncertainty is higher. Moreover, we find that the estimated coefficients on TIV remain negative and significant.[22]

[21] Since one might suspect that some of the results could be driven by the large increase in interest rate uncertainty during the 2008/2009 financial crisis, we also present results excluding the crisis in the online appendix.

[22] In order to calculate the Hoberg and Maksimovic (2015) financial constraint measure, firms must have a machine readable Capitalization and Liquidity Subsection in their 10-K which limits the number of firms and explains the drop in observations in specification (6) compared to other regressions.

Further Evidence The importance of financing constraints support the relevance of a cash flow mechanism underlying the negative link between TIV and corporate investment, as predicted by our model in Table 6. Table 9 provides further evidence from a related angle. If uncertainty about future interest payments affects firms' investment decisions in periods of elevated interest rate uncertainty, we would expect the effect to be stronger in more highly levered firms, and irrelevant for unlevered companies. In contrast, a negative link between TIV and investment in unlevered firms could be attributed to standard real option effects.

[insert Table 9 here]

The second column in Table 9 confirms that the effect in more highly levered firms is indeed stronger, as can be seen from the significant interaction term with book leverage. We next consider, going beyond our sample of firms, a sample of unlevered companies, sometimes referred to as zero leverage firms (see e.g., Strebulaev and Yang (2013)).[23] In that sample, the point estimate is no longer statistically significantly different from zero suggesting that the cash flow effect is absent in these firms, and equally importantly, there is no evidence that the real options effect is at work either. Notably, in unreported results, we find that the VIX still significantly negatively predicts investment in unlevered firms, suggesting that equity market uncertainty works through a different, possibly the real options, channel.

In a similar vein, uncertainty about future interest payments should be strongly linked to the amount of floating rate debt in firms' debt structures, or relatedly, the amount of bank debt (which tends to come with floating rates). We explore this link in Table 10, where we further include measures of bank and floating rate debt and their interactions with TIV in our regressions. The table shows that the interaction terms are indeed significantly negative, so that firms with more floating rate or bank debt cut back more on investment in times of high interest rate uncertainty.

[insert Table 10 here]

[23] There are 349 zero leverage firms in our data set.

4.2 Interest rate risk management in the cross-section

The relevance of the cash flow mechanism suggests a role for interest rate risk management, as uncertainty about future interest payments can be hedged in the swap market. Before examining the links between hedging and corporate investment, we provide some evidence and tests of our model predictions regarding the cross-sectional determinants of corporate interest rate risk management practices.

Model Tests To shed some light on the cross-sectional determinants of swap usage, we sort swap usage into terciles based on several firm characteristics along the model predictions (size, net worth, long-term debt, Tobin's Q, % floating rate debt) as well as similar variables readily available empirically (bank debt, cash, and age).[24] The results are reported in Table 11. Panel A sorts % amount swapped, while Panel B sorts the |% swapped|. We first note that the patterns are qualitatively strikingly similar to those predicted in Table 5, based on model simulations, where applicable. Panel A, first column, shows that small firms are fixed rate payers and swap on average 8.1% of their outstanding debt, while large firms are floating rate payers and swap on average 2.7% of their initial exposure. Broadly, smaller, younger firms and firms with lower net worth and higher growth opportunities tend to swap significantly more and tend to be fixed rate payers, as opposed to firms at more advanced stages of their life-cycle.

[insert Table 11 here]

Similar patterns emerge with regard to swap usage in absolute terms, where we find that smaller and younger, and firms with lower net worth hedge significantly more, similar to firms holding more cash and more short-term debt, with higher Tobin's Q. Clearly, these firm characteristics are inherently linked, and the linkages become apparent through the lens of our model: Smaller firms have higher growth opportunities, but have more volatile cash flows and primarily rely on short-term, floating rate (bank) debt, so that they end up hedging more, using cash and swapping the floating-to-fixed rate payments. In the data, smaller firms tend to be younger and hold more cash, as well.

Further Evidence The previous discussion suggests that firms linked to characteristics that are associated with higher financial constraints (such as lower size, net worth, age) tend to hedge more in

[24] Note that we only use the sample of swap users.

absolute terms and end up taking the fixed rate legs of the contracts. Table 12 adds further empirical content to that discussion by relating swap usage to financial constraint indicators and financial distress by means of double sorts. In Panel B of Table 12 we make use of size, while Panel C reports double-sorts using firms' net worth. A common concern with empirical financial constraints indices is that they do not clearly differentiate between financially constrained and financially distressed firms. While financial constraints prevent firms from exercising growth options, financially distressed firms are on the verge to default, a trait more widely associated with mature and older firms that have exhausted their growth potential. To account for these differences, we use the simplest measure of financial distress, corporate credit spreads.[25]

[insert Table 12 here]

Panel A shows univariate sorts of absolute percentage swapped on measures of financial constraints and distress. The empirical patterns that emerge are that distressed firms hedge less and constrained firms hedge more, with the differences mostly being highly statistically significant. As Panels B and C show, these patterns also hold up in two-way sorts along the constraint and distress measures.

Table 13 gives a sense of the implications of these cross-sectional differences in hedging policies for firms' interest rate risk exposure, as measured by cash flow betas and volatilities, and provides tests of the model predictions in this regard in Panel C of Table 5. The tests are quite revealing in that even post hedging, firms with characteristics associated with higher financial constraints exhibit higher exposure to movements in interest rates even though they hedge more, also statistically significantly so, in line with our theoretical predictions. Through the lens of the model, this pattern is readily rationalized as firms with traits of higher financial constraints tend to have considerably more floating rate debt in their capital structure. Hedging not only requires ex ante fixed costs, but can consume resources ex post depending on the realization of the interest rate, which may trigger additional costs of external finance, so that incomplete hedging may be optimal in the presence of financial frictions. In this sense, model and data suggest that constrained firms hedge more, but "too little".

[insert Table 13 here]

[25] The online appendix shows results using firms' expected default frequency and we find them to be quantitatively the same as for credit spreads.

4.3 Interest rate uncertainty, risk management, and corporate policies

Finally, we examine empirically how the possibility of interest rate risk management impacts the effects of interest rate uncertainty on corporate policies.

Model Tests We start by testing our model's predictions regarding the effects of interest rate uncertainty and hedging on future investment, as laid out in Table 6. Our empirical results suggest that any adverse effects of interest rate uncertainty on real outcomes are transmitted through a cash flow channel, and our model predicts that the possibility of hedging should affect that link. In Table 14, we report results to that effect. Panel A documents that risk management significantly attenuates the adverse effects of interest rate uncertainty on investment in financially constrained firms. The interaction term of TIV with any of the hedging variables is positive and significant. Accordingly, the impact of interest rate uncertainty on corporate investment significantly depends on hedging activity and liquidity positions for constrained firms. On the other hand, it is quite revealing that all these effects are indistinguishable from zero in financially unconstrained firms, as documented in Panel B where we find none of the interaction terms to be statistically significant.

[insert Table 14 here]

Further Evidence Finally, we present further evidence of firms' risk management policies in the presence of interest rate uncertainty. Table 15 (Panel A) reports results from predictive panel regressions of firm level variables such as next year's cash, |% swapped|, hedging, and debt composition on TIV and a battery of firm level controls.[26]

[insert Table 15 here]

The results indicate that after rises in interest rate uncertainty firms hold more cash, swap significantly more and reduce floating rate debt in their debt structure. This is consistent with the intuition that in response to elevated interest rate uncertainty, firms become more cautious and engage more in hedging. Panel B presents robustness tests from estimates obtained using the first-difference GMM

[26] All t-statistics are calculated using robust asymptotic standard errors which are clustered at the firm and year level.

estimator, proposed by Arellano and Bond (1991), which controls both for unobserved firm-specific heterogeneity and for possible endogeneity of the regressors.[27]

5 Conclusion

We revisit the large literature documenting negative links between uncertainty shocks and real activity in the context of a particular manifestation of uncertainty which can readily be hedged in derivatives markets, namely interest rate uncertainty. Indeed, the market for interest rate swaps is one of the most active in the world as indicated by its daily trading volume of close to $3 trillion. We first document that rises in interest rate uncertainty - driven by either uncertainty about future economic outcomes or about future actions of monetary authorities - predict a significant slowdown in real activity over and beyond alternative uncertainty or business cycle indicators. We then develop a model that links corporate investment and financing to interest rate uncertainty to examine how firms cope with interest rate uncertainty when they have access to derivatives markets for hedging purposes. Empirical tests using a rich dataset on corporate swap usage confirm the model predictions that small and constrained firms are most exposed to interest rate uncertainty and hedging it, while beneficial, also exposes them to substantial risk, so that interest rate uncertainty significantly depresses their investment. Ultimately, risk management by means of swaps can be risky, especially for financially constrained firms.

Through the lens of the model, our empirical findings are consistent with an economic environment in which adverse movements in interest rate uncertainty are a source of slowdowns in economic activity. In this context, scenarios that reduce monetary policy uncertainty, such as uncertainty about the future path of the short-term interest rate as the Federal Reserve's main policy instrument, for example, by means of effective forward guidance, appear beneficial. Clearly, the Fed's actions reflect numerous margins and trade-offs that are left unmodeled here. Modeling and analyzing monetary policy trade-offs and choices in the context of interest rate uncertainty is an important and challenging topic that we leave for future research.

[27] The GMM panel estimator relies on first-differencing the regression equation to eliminate firm-specific fixed effects, and uses appropriate lags on the right-hand side variables as instruments. To save space, we only report estimated coefficients for the TIV and find the results to remain qualitatively the same.

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6 Appendix

In this appendix, we provide a more detailed description of the firm-level data used in our empirical work.

Firm determinants: To study determinants of firms' hedging activity, we also gather firm-specific information from Compustat. We calculate market *leverage* as total debt (long-term debt, DLTT, plus debt in current liabilities, DLC) divided by the market value of the firm which is calculated as book assets (AT) minus book equity (CEQ) plus the product of the share price at the end of the fiscal year (PRCC_F) and the number of shares outstanding (CSHO). We define net worth as in Rampini, Sufi, and Viswanathan (2013): book assets (AT) minus book equity (CEQ) plus the product of the share price at the end of the fiscal year (PRCC_F) and the number of shares outstanding (CSHO) minus book equity minus deferred taxes (TXDB) minus total liabilities (LT). Following Chernenko and Faulkender (2011), we calculate the percentage of debt that has more than five years to maturity as the difference between the overall amount of long-term debt (DLTT) and debt maturing in years two through five (DD2 - DD5), divided by total debt. This variable is referred to as *long-term debt*. The explanatory variable *cash* is cash (CH) scaled by book assets. We then merge this data with the Capital IQ database, which contains information on firms' usage of bank debt and floating-rate debt. Following Ippolito, Ozdagli, and Perez (2015), we define *bank debt* as the sum of term loans (IQ_TERM_LOANS) and drawn credit lines (IQ_RC) divided by total assets (AT). Because of the lack of wide coverage of bank debt data in CIQ before 2001, we focus on a sample period from 2001 to 2014 whenever we rely on data from the Capital IQ database.

A firm's *profitability* is measured as the ratio of operating income before depreciation (OIBDP) to book assets. Motivated by Froot, Scharfstein, and Stein (1993), we also include the sum of capital expenditures (CAPX) and acquisitions (AQC) scaled by book assets as a measure of *investment* in our analysis. Finally, we introduce *total hedging* as an alternative hedging variable. Risk management can take place both through derivatives usage and cash. The latter enables firms to forestall distress and default. Motivated by Bolton, Chen, and Wang (2011), we calculate this variable as the sum of cash and the absolute value of the net notional amount of interest swaps outstanding scaled by book assets. To estimate each firm's cash flow interest rate beta, we regress free cash flow for a given year on the average value of the three-month LIBOR during that year.[28] Cash flow volatility is the standard deviation of annual free cash flows of a firm during the sample period.

We also use aggregate Tobin's Q and leverage in our regressions. To this end, we follow Jovanovic and Rousseau (2014) and calculate market leverage and Q as the value-weighted average of quarterly averages of firm-specific leverage and Q's.

Financial constraint measures: Following Whited and Wu (2006), we construct a financial constraints index, henceforth WW index, which is based on the coefficients from a structural model. More specifically, a firm is defined to be financially constrained if it would like to raise an additional dollar of external capital but cannot do so because it faces a vertical supply of external capital curve. We also make use of a text-based financial constraints index as in Hoberg and Maksimovic (2015) who analyze firms' 10-K reports with a focus on mandated disclosures regarding each firm's liquidity. In addition to these two measures, we also use the Hadlock and Pierce (2010) index.

Financial distress: To measure financial distress, we use two different variables: i) credit default swap (CDS) data and ii) probabilities of default. We obtain daily CDS data for the period from 2002

[28] To get more precise estimates, we require firms to have at least 5 observations in order to estimate their cash flow interest rate beta. Firms with fewer observations have missing values of cash flow interest rate beta but remain in the sample and are used in specifications that do not include cash flow interest rate beta.

to 2014 from Markit. In our analysis, we merge the monthly average of the five-year credit spreads in the respective fiscal-year-end month for each company in every year. We focus on five-year credit spreads as they are the most liquid for the sample period. In addition, we also use firm level expected probability of default (EPD) data which comes from the Risk Management Institute at National University of Singapore. A firm's probability of default is the cleanest measure of default risk as CDS prices or ratings can be driven by factors other than credit risk. We have monthly EPDs for the period from 1994 to 2014. To allow for a comparison of the results, we also focus on the five-year EPD in the respective fiscal-year-end month for each company in every year.

7 Tables

Table 1
Predicting aggregate investment

This table shows predictive regressions from aggregate investment onto different variables. Each column shows the results for a specific model. In addition to the reported explanatory variables, each specification also includes a constant and p lags of the dependent variable, i.e. aggregate investment (not reported). The optimal lag length p is determined by the Bayesian information criterion (BIC). The asymptotic t-statistics are reported in parentheses. In particular, for forecasting horizons $h \geq 1$, the MA(h) structure of the error term ϵ_{t+h} induced by overlapping observations is taken into account by computing standard errors according to Hodrick (1992). TIV is an implied volatility index from Treasury future options. Aggregate investment is measured using real gross private domestic investment. tiv - policy refers to the residuals from a linear regression of TIV on a constant term and the economic policy uncertainty index by Baker, Bloom, and Davis (2016). tiv - financial (tiv - macro) refers to the residuals from an analogous regression on the financial (macro) uncertainty index by Jurado, Ludvigson, and Ng (2015). Finally, tiv - forecast are the residuals from regressing TIV on GDP growth forecasts. All regression coefficients are standardized. The sample period is from 1994 to 2014.

model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
tiv	-0.365	-0.533		-0.439	-0.414								
	(-3.66)	(-3.97)		(-8.66)	(-2.89)								
tiv - policy						-0.398	-0.318						
						(-5.07)	(-2.85)						
tiv - financial								-0.364	-0.318				
								(-9.75)	(-4.72)				
tiv - macro										-0.320	-0.289		
										(-8.06)	(-2.64)		
tiv - forcast												-0.348	-0.316
												(-5.71)	(-7.76)
term spread		-0.799	-0.249	-0.495	-0.626	-0.776	-0.634	-0.652	-0.532	-0.676	-0.554	-0.662	-0.544
		(-6.69)	(-1.40)	(-2.36)	(-4.65)	(-11.86)	(-4.78)	(-13.49)	(-11.64)	(-12.50)	(-5.13)	(-13.52)	(-8.89)
fed fund rate		0.384	-0.168	-0.079	0.169	0.465	0.273	0.284	0.095	0.320	0.114	0.331	0.128
		(2.48)	(-1.01)	(-0.38)	(1.03)	(5.56)	(1.49)	(3.07)	(0.80)	(2.25)	(0.67)	(3.08)	(1.09)
gz spread			-0.637	-0.485									
			(-3.88)	(-4.12)									
baa - aaa					-0.314		-0.249		-0.345		-0.383		-0.376
					(-3.66)		(-2.00)		(-4.77)		(-6.52)		(-6.08)
vix						-0.228	-0.186	-0.269	-0.187	-0.216	-0.127	-0.192	-0.106
						(-2.10)	(-1.66)	(-2.06)	(-1.68)	(-1.97)	(-1.65)	(-1.41)	(-1.00)
Tobin's Q		0.270	0.575	0.671	0.401	0.312	0.406	0.361	0.459	0.359	0.462	0.365	0.465
		(3.08)	(7.32)	(9.88)	(2.93)	(2.04)	(2.59)	(2.37)	(2.57)	(2.75)	(2.87)	(2.16)	(2.44)
leverage		0.526	0.704	0.823	0.657	0.492	0.602	0.655	0.755	0.677	0.784	0.647	0.755
		(4.46)	(6.19)	(10.47)	(4.14)	(2.87)	(3.65)	(3.66)	(3.73)	(4.37)	(4.22)	(3.60)	(3.55)
gdp growth	0.519	0.404	0.396	0.281	0.348	0.442	0.393	0.423	0.345	0.459	0.364	0.443	0.352
	(4.90)	(4.87)	(2.20)	(2.13)	(4.91)	(6.91)	(6.26)	(4.78)	(5.14)	(5.43)	(7.52)	(4.46)	(4.80)
Adj. R2	53.71%	60.95%	65.53%	69.43%	63.75%	62.72%	64.09%	61.05%	64.89%	58.00%	62.96%	59.29%	64.06%

Table 2
Swap usage and floating rate debt summary statistics

This table reports summary statistics for swap usage and floating rate debt percentages for the sample of non-financial firms. Swap users are firms that use interest rate swaps at least once during the sample period. Initial % floating is the percentage of outstanding debt that is floating before accounting for the effect of interest rate swaps. % floating is the percentage of outstanding debt that is floating after accounting for the effect of interest rate swaps. % swapped is the percentage of outstanding debt that is swapped to a floating interest rate and |% swapped| is the absolute value of this. Long-term debt is the percentage of outstanding debt that has more than five years to maturity. The sample period runs from 1994 to 2014.

	N	mean	stdev	min	max
initial % floating	17,631	37.423	31.484	0	100
% swapped	19,304	-1.685	17.123	-100	100
|% swapped|	19,304	6.877	15.771	0	100
% floating	17,631	35.818	29.466	0	100
long-term debt	17,389	40.038	31.948	0	100

Table 3
Calibration

This table summarizes the calibration used to solve and simulate our model (Panel A) and the unconditional moments of corporate policies and interest rates generated by the model (Panel B). All quantities are annual.

Panel A: Calibration

Description	*Parameter*	*Value*
Interest rate persistence	ρ_r	0.86
Interest rate volatility persistence	$\rho_{\sigma r}$	0.41
Interest rate volatility vol	σ_w	0.0002
TFP persistence	ρ_x	0.85
TFP volatility persistence	$\rho_{\sigma x}$	0.85
TFP volatility vol	σ_ζ	0.007
Price of interest rate risk	λ_r	-21
Price of interest volatility risk	λ_σ	-5
Price of profitability risk	γ_x	2
Price of volatility risk	γ_σ	0
Persistence of idiosyncratic shock	ρ_z	0.76
Volatility of idiosyncratic shock	σ_z	0.2
Capital share	α	0.65
Fixed costs of production	f	0.03
Corporate tax rate	τ	0.14
Bankruptcy costs	ξ	0.2
Fixed equity issuance costs	λ_0	0.03
Proportional equity issuance costs	λ_1	0.05
Swap issuance costs	ψ	0.001
Depreciation rate	δ	0.12

Panel B: Moments

Moment	*Data*	*Model*
Average investment rate	0.15	0.14
Average market leverage	0.28	0.31
Dispersion in market leverage	0.41	0.34
Average long term debt ratio	0.69	0.62
Frequency of equity issuances	0.07	0.03
Average equity issuance over assets	0.09	0.07
Average market-to-book ratio	2.25	1.58
Average profitability	0.15	0.12
Short-rate volatility	0.03	0.03
Short-rate autocorrelation	0.83	0.83
One-year credit spread	0.007	0.013
Ten-year credit spread	0.013	0.019
Five-year term spread	0.74	0.72
Ten-year term spread	1.27	1.21
Five-year term spread vol	0.92	0.68
Ten-year term spread vol	1.32	1.35
Fraction of swap users	0.63	0.61
Absolute percentage swapped	0.068	0.046
Net percentage swapped	-0.016	-0.027

Table 4
Predicting aggregate investment: Model

This table reports estimated coefficients from predictive regressions of one-year ahead aggregate investment growth, ΔI_{t+1}, on interest rate uncertainty, σ^2_{rt}, and controls, in simulated data. Aggregate quantities are aggregated from simulated panels of 1,600 firms over a period of 20 years. Standard errors are Newey and West (1987) adjusted. R^2 is adjusted for degrees of freedom. Model (1) is the benchmark model, model (2) keeps aggregate profitability volatility constant, and model (3) keeps both aggregate profitability as well as aggregate profitability volatility constant.

model	(1)	(2)	(3)
tiv	-0.271	-0.238	-0.125
	(-2.57)	(-2.42)	(-2.37)
gdp growth	0.652	0.623	0.594
	(3.12)	(3.24)	(3.29)
Adj. R2	62%	64%	64%

Table 5

Tercile sorts of swap usage and cash flow betas and volatility: Model

This table reports univariate tercile sorts of % swapped (Panel A) and |% swapped| (Panel B) along size, net-worth, Tobin's Q, long-term debt and % floating from model simulations. Panel C reports univariate tercile sorts of cash flow betas with respect to interest rates and volatility along size.

h	size	nworth	Tobin's Q	lt debt	% floating
Panel A: % swapped					
low	-7.557	-7.124	2.446	-7.306	2.296
mid	-3.312	-3.268	-3.237	-3.244	-3.303
high	2.473	1.996	-7.605	2.154	-7.389
Panel B: |% swapped|					
low	7.723	7.702	2.626	7.654	2.572
mid	3.478	3.649	3.512	3.615	3.597
high	2.611	2.461	7.674	2.543	7.643
Panel C: CF Betas & Vol					
low		1.174	13.145		
mid		1.049	11.426		
high		0.938	9.738		

Table 6
Predicting firm-level investment: Model

This table reports estimated coefficients from simulated panel regressions of one-year ahead firm's investment on interest rate uncertainty and firm-specific variables. Estimated coefficients are based on simulations of 1,600 firms over a period of 20 years. Firm fixed effects are included and standard errors are clustered at the firm level.

tiv	-0.010	-0.013	-0.012	-0.016	-0.012
	(-2.26)	(-2.33)	(-2.32)	(-2.15)	(-2.30)
tiv * size		0.011			
		(2.09)			
tiv * nworth			0.009		
			(2.31)		
tiv * leverage				-0.012	
				(-2.37)	
tiv * |%swapped|					0.010
					(2.17)
nworth			0.022		
			(2.43)		
|%swapped|					0.007
					(2.13)
size	-0.176	-0.159	-0.189	-0.167	-0.182
	(-2.82)	(-2.96)	(-2.80)	(-2.87)	(-2.73)
leverage	-0. 161	-0.153	-0.162	-0.109	-0.131
	(-2.14)	(-2.06)	(-2.20)	(-2.18)	(-2.21)
Tobin's Q	0.422	0.396	0.365	0.323	0.318
	(3.65)	(3.75)	(3.49)	(3.57)	(3.62)
Adj. R2	52%	56%	61%	55%	56%

Table 7
Counterfactuals

This table reports the coefficients of panel regressions of next year's investment on interest rate uncertainty, and controls, in the data and in various model specifications. The empirical measure for interest rate uncertainty used here is realized variance on a one-year constant maturity Treasury yield, and its model counterpart is conditional variance σ^2_{rt}. The empirical sample period runs from 1994 to 2014, with a model counterpart of 20 periods. Model (i) is the benchmark model, (ii) features fully reversible investment, (iii) features equity financing only, (iv) has no swaps, (v) reduces the standard deviation of idiosyncratic profitability shocks by half, and (vi) sets interest rate volatility to its mean.

variable	data	model					
		(i)	(ii)	(iii)	(iv)	(v)	(vi)
IRU coeff	-0.006	-0.010	-0.009	-0.003	-0.016	-0.007	-
Avg market leverage	0.28	0.31	0.36	0.00	0.29	0.39	0.34
Frequency of equity issuance	0.07	0.03	0.04	0.06	0.05	0.04	0.04
Avg absolute swap position	0.028	0.015	0.017	0.011	0.00	0.024	0.014
Avg investment rate	0.15	0.14	0.17	0.16	0.13	0.18	0.16

Table 8
Firm level investment: financially constrained vs unconstrained firms

This table reports predictive panel regressions with firms' future investment as a dependent variable. *tiv* refers to the Treasury implied volatility; *size* is the logarithm of a firm's total assets; *nworth* is the firm's net worth; *ww* is the Whited and Wu (2006) index of financial constraints; *hm* is the Hoberg and Maksimovic (2015) general index of liquidity constraints; *hp* is the Hadlock and Pierce (2010) index of financial constraints; *kz* is the Kaplan and Zingales (1997) index of financial constraints. All specifications also include a constant term and firm fixed effects (not reported). Standard errors are clustered at the firm and year level. R^2 is adjusted for degrees of freedom. The sample period runs from 1994 to 2014.

model	(1)	(2)	(3)	(4)	(5)	(6)
tiv	-0.002	-0.006	-0.002	-0.004	-0.010	-0.003
	(-2.58)	(-2.78)	(-3.05)	(-2.86)	(-2.98)	(-3.89)
tiv*size		0.000				
		(1.82)				
tiv*nworth			0.044			
			(3.75)			
tiv*ww				-0.004		
				(-1.88)		
tiv*hp					-0.002	
					(-2.22)	
tiv*hm						-0.006
						(-2.43)
net worth			-0.002			
			(-0.03)			
ww				0.039		
				(1.88)		
hp					-0.020	
					(-1.06)	
hm						0.003
						(1.99)
size	-0.018	-0.021	-0.021	-0.019	-0.022	-0.016
	(-6.51)	(-6.65)	(-7.21)	(-6.00)	(-6.30)	(-4.85)
leverage	-0.009	-0.009	-0.010	-0.010	-0.009	-0.010
	(-7.52)	(-7.51)	(-7.50)	(-7.19)	(-7.58)	(-5.70)
Tobin's Q	0.008	0.008	0.008	0.007	0.007	0.008
	(5.65)	(5.68)	(5.23)	(5.28)	(5.61)	(5.10)
long-term debt	0.006	0.006	0.005	0.008	0.006	0.002
	(1.67)	(1.66)	(1.43)	(2.11)	(1.56)	(0.34)
gdp	0.208	0.209	0.204	0.184	0.201	0.162
	(2.53)	(2.61)	(2.45)	(2.26)	(2.51)	(2.54)
Firm FE	Y	Y	Y	Y	Y	Y
Clustered by Firm & Year	Y	Y	Y	Y	Y	Y
Adj. R2	32.28%	32.31%	32.36%	31.92%	32.35%	34.74%
N	13,129	13,129	12,117	10,144	13,129	8,805

Table 9
Firm level investment: zero leverage firms

This table reports predictive panel regressions with firms' future investment as a dependent variable. The sample of zero leverage firms includes all Compustat firms that have no debt outstanding during our entire sample period, available data for at least five consecutive years, and total assets larger than $5 million (total 349 firms). Zeroleverage is a dummy variable that equals 1 for a zero leverage firm and 0 otherwise. The last column shows regression results for the combined samples, i.e. our sample and all zero leverage firms. All specifications also include a constant and firm fixed effects (not reported). Standard errors are clustered at the firm and year level. R^2 is adjusted for degrees of freedom. The sample period runs from 1994 to 2014.

	Full Sample				Only ZL	Combined
tiv	-0.002	-0.004	-0.004	-0.003	-0.000	-0.003
	(-2.58)	(-5.05)	(-5.15)	(-4.29)	(-0.40)	(-3.99)
tiv*leverage		(-0.00)				
		(-2.47)				
tiv*bookleverage			-0.001			
			(-2.91)			
tiv*zeroleverage						0.002
						(3.44)
bookleverage			-0.005			
			(-2.89)			
size	-0.018	-0.006	-0.017	-0.015	0.014	-0.013
	(-6.51)	(-3.91)	(-6.39)	(-6.35)	(2.37)	(-5.41)
leverage	-0.009	-0.018				
	(-7.52)	(-6.56)				
Tobin's Q	0.008	0.008	0.011	0.008	0.005	0.007
	(5.65)	(5.58)	(8.77)	(7.41)	(3.36)	(8.57)
long-term debt	(0.01)	(0.00)	(0.00)			
	(1.67)	(1.16)	(1.06)			
gdp	0.208	0.157	0.155	0.145	0.126	0.156
	(2.53)	(2.50)	(2.44)	(2.14)	(1.77)	(2.50)
Firm FE	Y	Y	Y	Y	Y	Y
Clustered by Firm & Year	Y	Y	Y	Y	Y	Y
Adj. R2	32.28%	32.29%	32.13%	29.87%	2.74%	31.41%
N	13,129	12,013	12,013	15,938	1,957	17,895

Table 10
Firm level investment: bank loans and floating-rate debt

This table reports predictive panel regressions with firms' future investment as a dependent variable. *bank debt* is defined as the sum of term loans and drawn credit lines divided by total assets. *floating rate debt* is floating rate debt including swap effects divided by total assets. All specifications also include a constant and firm fixed effects (not reported). Standard errors are clustered at the firm and year level. R^2 is adjusted for degrees of freedom. The sample period runs from 1994 to 2014.

tiv	-0.002	-0.002
	(-3.06)	(-2.90)
tiv*bank debt	-0.002	
	(-1.95)	
tiv*floating debt		-0.007
		(-2.33)
bank debt	-0.064	
	(-3.56)	
floating debt		-0.022
		(-0.87)
size	-0.012	-0.020
	(-2.94)	(-6.91)
leverage	-0.009	-0.011
	(-4.97)	(-5.68)
Tobin's Q	0.009	0.008
	(4.67)	(5.07)
long-term debt	0.005	0.001
	(1.24)	(0.14)
gdp	0.105	0.151
	(1.99)	(2.29)
Firm FE	Y	Y
Clustered by Firm & Year	Y	Y
Adj. R2	34.95%	34.10%
N	9,057	10,483

Table 11
Tercile sorts of swap usage

This table reports univariate tercile sorts of % swapped along size, long-term debt, cash, and Tobin's Q (Panel A), and on |% swapped|(Panel B). The rows "High - Low" test whether "High" is statistically different from "Low". *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The data cover the period from 1994 to 2014.

	size	nworth	lt debt	Tobin's Q	% floating	Bank debt	cash	age
Panel A: % swapped								
low	-8.114	-6.713	-8.416	-3.051	6.670	4.500	-3.791	-5.155
mid	-1.721	-3.187	0.460	-1.729	1.240	2.868	-2.960	-3.464
high	2.671	3.152	1.462	-1.106	-12.378	-12.193	0.319	1.799
total	-2.211	-2.175	-2.117	-2.045	-1.952	-1.835	-2.221	-2.211
high - low	10.785***	9.865***	9.878***	1.945***	19.048***	16.693***	4.110***	6.953***
Panel B: |% swapped|								
low	10.545	9.483	12.101	8.213	6.090	8.164	8.977	10.833
mid	9.518	9.297	7.929	9.252	6.953	8.967	9.289	9.573
high	7.826	8.113	7.471	10.594	13.878	14.053	9.532	7.446
total	9.253	8.955	9.145	9.234	8.995	10.448	9.257	9.253
high - low	2.719***	1.370***	4.630***	2.381***	7.789***	5.889***	0.554*	3.387***

Table 12

Double sorts of |% swapped|

Panel A reports univariate sorts of |% swapped|along terciles of five-year credit spread, five-year expected probability of default (EPD), size, and net worth. The rest of the table reports unconditional double sorts of |% swapped|along size and credit spreads (Panel B) and net worth and credit spreads (Panel C). The columns and rows labeled "High - Low" test whether "High" is statistically different from "Low". *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The data cover the time period from 1994 to 2014.

Panel A: Univariate Sorts

	1	2	3	Total	Low - High
credit spread	9.946	8.394	7.945	8.766	2.001***
size	10.545	9.518	7.826	9.253	2.719***
nworth	9.483	9.297	8.113	8.955	1.370***

Panel B: Size & Credit Spread

	Credit Spread				
Size	Low	Mid	High	Total	Low - High
low	8.778	7.880	7.440	7.871	1.338*
mid	8.770	7.920	7.531	8.024	1.238*
high	9.922	8.326	7.630	8.998	2.291**
total	9.350	8.042	7.507	8.303	
low - high	1.144**	0.446*	0.190		

Panel C: Net Worth & Credit Spread

	Credit Spread				
nworth	Low	Mid	High	Total	Low - High
low	8.924	6.959	6.912	6.996	2.012*
mid	8.869	8.018	7.518	7.899	1.351*
high	9.129	8.273	7.636	8.580	1.493**
total	9.090	8.162	7.414	8.235	
low - high	0.205	1.313**	0.724*		

Table 13
Tercile sorts of cash flow betas and volatility

This table reports univariate tercile sorts of cash flow betas (Panel A) and cash flow volatility (Panel B) along size, net worth, WW-, HP, and HM-indices. The rows "High - Low" test whether "High" is statistically different from "Low". *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level. The data cover the period from 1994 to 2014.

	size	nworth	ww	hp	hm
Panel A: Cash Flow Betas					
low	1.466	1.420	1.117	0.832	1.206
mid	1.358	1.318	1.254	1.390	1.335
high	1.112	1.160	1.554	1.854	1.495
total	1.286	1.302	1.282	1.286	1.340
high - low	0.354***	0.260***	0.437***	1.022***	0.290***
Panel B: Cash Flow Volatility					
low	11.072	10.386	7.924	6.173	9.124
mid	9.578	9.234	9.498	9.114	9.253
high	7.516	7.910	10.978	11.970	10.137
total	9.100	9.185	9.276	9.100	9.485
high - low	3.556***	2.476***	3.054***	5.797***	1.013***

Table 14
Corporate hedging and investment: constrained vs unconstrained firms

This table reports predictive panel regressions with firms' future investment as a dependent variable for financially constrained and unconstrained firms. A firm is considered financially constrained if its net worth lies in the bottom tercile for the sample in a given year, otherwise a firm is considered financially unconstrained. *tiv* is the Treasury implied volatility; |%*swapped*| is the absolute value of the net share of the firm's debt that is swapped using interest rate swaps; *hedging* is the sum of a firm's cash holdings and |% swapped|; and *cash* refers to a firm's cash holdings. All specifications also include a constant and firm fixed effects (not reported). Standard errors are clustered at the firm and year level. R^2 is adjusted for degrees of freedom. The sample period runs from 1994 to 2014.

	Constrained Firms			Unconstrained Firms		
tiv	-0.005	-0.004	-0.004	-0.002	-0.003	-0.003
	(-2.54)	(-2.63)	(-2.81)	(-4.20)	(-4.77)	(-4.23)
tiv*|% swapped|	0.006			-0.003		
	(2.32)			(-1.60)		
tiv*hedging		0.008			-0.001	
		(2.00)			(-0.24)	
tiv*cash			0.011			0.001
			(2.73)			(0.11)
|% swapped|	-0.004			0.008		
	(-0.81)			(0.54)		
hedging		0.000			0.034	
		(0.01)			(0.87)	
cash			0.001			0.082
			(0.17)			(1.46)
Controls	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Cluster by Industry & Year	Y	Y	Y	Y	Y	Y
Adj. R2	25.04%	25.85%	26.19%	35.56%	34.49%	34.75%
N	1,424	2,442	2,452	6,568	9,060	9,097

Table 15
Interest rate uncertainty and corporate hedging: panel regressions

Panel A reports predictive panel regressions that take as dependent variable either a firms's future *cash* holdings; the absolute value of the net share of the firm's debt that is swapped using interest rate swaps, $|\%swapped|$; *hedging* is the sum of a firm's cash holdings and |% swapped|; and $\%floating$ is percentage of a firm's debt with floating interest rate. *tiv* refers to the Treasury implied volatility. All specifications also include a constant term and firm fixed effects (not reported). Standard errors are clustered at the firm and year level. R^2 is adjusted for degrees of freedom. Panel B reports the robust estimators according to Arellano and Bond (1991) for the *tiv*. For the regression specification with future $|\%swapped|$ as a dependent variable these tests are not feasible since the original specification in panel A does not include a lag of the dependent variable as a control. Standard errors in panel B are robust for heteroscedasticity. The sample runs from 1994 to 2014.

	cash	|% swapped|	hedging	% floating
Panel A: Corporate Hedging				
tiv	0.001	0.003	0.002	-0.003
	(1.79)	(2.67)	(2.05)	(-1.77)
size	-0.001	0.003	-0.002	-0.019
	(-0.57)	(0.55)	(-0.51)	(-3.42)
leverage	-0.002	0.011	0.000	-0.016
	(-2.03)	(4.49)	(0.00)	(-4.47)
long-term debt	0.001	-0.024	0.001	-0.067
	(0.28)	(-2.80)	(0.33)	(-6.26)
Tobin's Q	-0.000	-0.003	-0.001	-0.003
	(-0.05)	(-1.30)	(-0.28)	(-0.70)
gdp	-0.146	0.176	-0.067	0.377
	(-2.86)	(1.39)	(-1.20)	(3.25)
Lagged LHS	Y	N	Y	Y
Firm FE	Y	Y	Y	Y
Clustered by Firm & Year	Y	Y	Y	Y
Adj. R2	67.27%	31.47%	59.19%	60.14%
N	12,746	11,979	12,685	11,085
Panel B: Robustness Test				
Arellano/Bond:				
tiv	0.001	NA	0.002	-0.002
	(4.99)		(4.39)	(-1.61)
Blundell/Bond:				
tiv	0.001	NA	0.001	-0.002
	(4.24)		(3.96)	(-1.73)

8 Figures

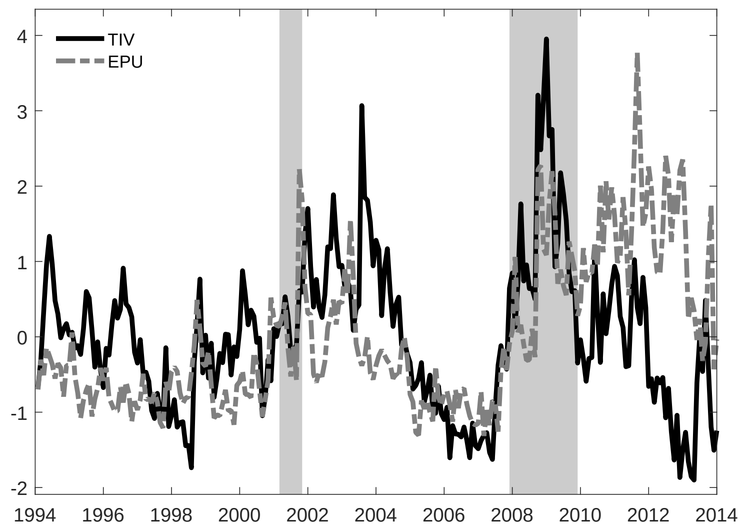

Figure 1. Interest Rate Uncertainty and Economic Policy Uncertainty

This figure plots a proxy of interest rate uncertainty (TIV) together with the economic policy uncertainty index (EPU) of Baker, Bloom, and Davis (2016). Both variables are standardized. Data are monthly and run from 1994 to 2014. Grey bars indicate NBER recessions.

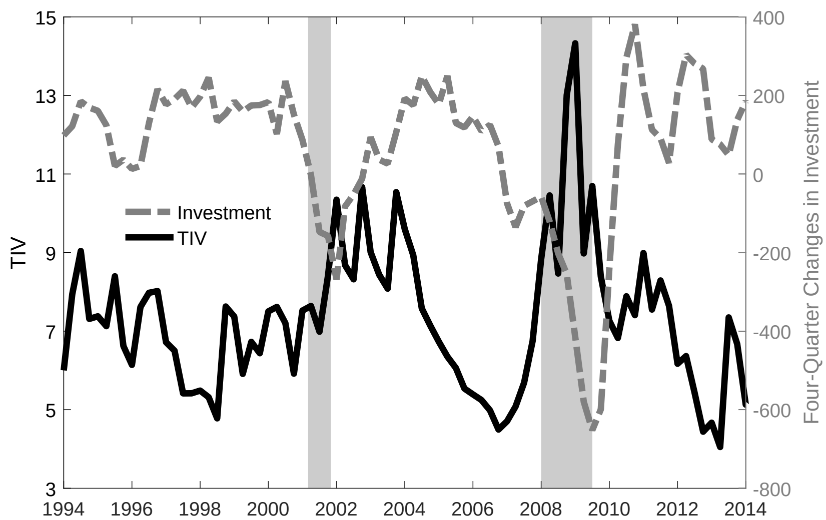

Figure 2. Interest Rate Uncertainty and Four Quarter Changes in Aggregate Investment
This figure plots interest rate uncertainty (solid line, left axis) together with four quarter changes in real gross private domestic investment (dashed line, right axis). Data are quarterly and run from 1994 to 2014. Grey bars indicate NBER recessions.

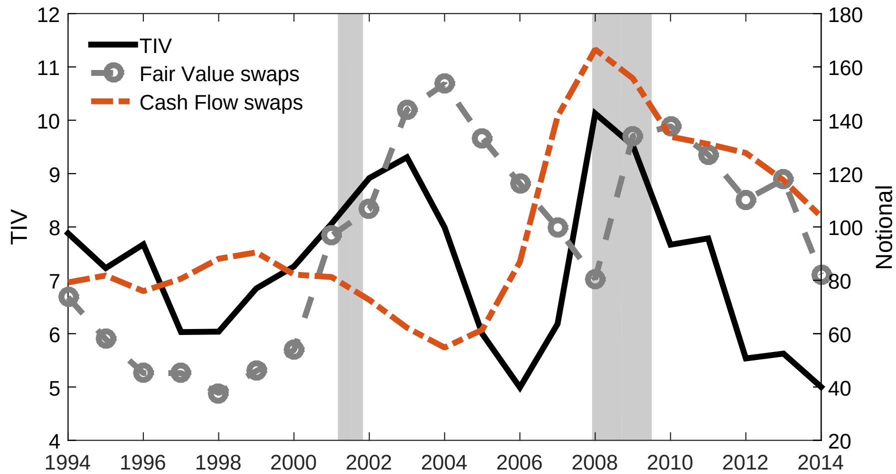

Figure 3. Swap Usage

This figure plots the annual time series of TIV (left axis, solid line), average cash flow swap (right axis, dashed line), and average fair value swap notionals (right axis, dashed line with markers). A cash flow swap transforms floating into fixed rate debt, whereas a fair value swap does the opposite. Data are annual and run from 1994 to 2014. Grey bars indicate NBER recessions.

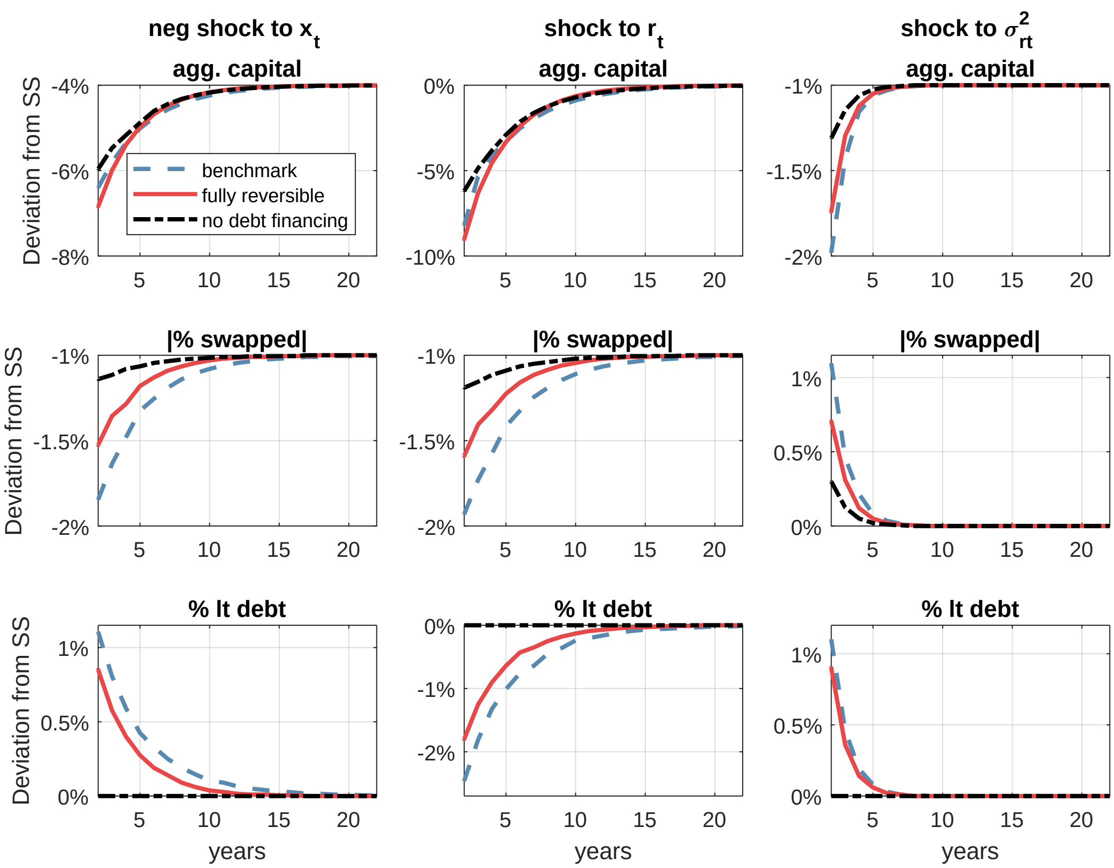

Figure 4. Impulse Response Functions

This figure plots impulse response functions from simulations when the economy is hit by a one standard deviation negative aggregate profitability shock, a positive interest rate shock, and a positive interest rate volatility shock, respectively, for aggregate capital, average absolute swap position, as well as the long-term debt share in firms' debt structures.