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Monetary Policy with Credit Market Frictions

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Abstract

I study the role of collateral as a source of financial friction in the transmission of monetary policy towards firms' investments. First, I use a panel of Swedish firms to estimate the heterogeneity in firm investment responses to monetary policy shocks conditional on collateral. I find that highly collateralized firms are more responsive to monetary policy and significantly reduce investments relative to firms with low collateral after a contractionary monetary policy shock. Moreover, I provide empirical evidence of collateral based borrowing constraints to support the evidence that investment responses to monetary policy vary with collateral. To motivate these results, I develop a New Keynesian model with heterogeneous credit constrained firms calibrated to the Swedish economy. The model generates results that are consistent with the empirical evidence in that firms with high collateral are more responsive to monetary policy. Overall, the findings have policy implications in that monetary policy is shown to be more powerful in achieving price stability when firms face credit frictions and are highly collateralized.

JEL classification: E12, E22, E32, E44, E58

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1 Introduction

The Great Recession has shown the crucial role that financial frictions play in amplifying business cycles and transmission of monetary policy. Consequently, the previous decade has witnessed the emergence of a macro-finance literature showing how financial market imperfections propagate macroeconomic shocks. I expand on this literature by studying the transmission of monetary policy to firms' and aggregate investments in the presence of collateral constraints.

Aggregate investment is the most volatile component of GDP[1] and one of the key channels for the transmission of monetary policy to the real economy. This makes investment outcomes both relevant and interesting to study in the context of monetary policy and collateral constraints. However, the important question is: how do collateral constraints interact with the transmission of monetary policy to firms' investments? The straightforward answer is through asset prices. Theoretically, a mechanism through which this transmission occurs can be explained as follows. Let's consider an economy where firms are required to pledge assets as collateral to secure loans from lenders to, for example, compensate for agency costs arising from potential moral hazard, adverse selection or state verification. Credit accessibility of firms then becomes tied to asset values. Suppose then that the economy experiences a positive monetary policy shock that increases the discount rate at which assets are priced hence, reducing the present market value of assets and therefore, collateral. The decline in collateral values constrains firms' access to credit and borrowing, which reduces the aggregate resources available to, for example, make investments. This dampens aggregate investments in the economy and results to macroeconomic contractions.

In this paper, I explore the aforementioned colleteral channel of monetary policy transmission to firms' investments using both empirical methods and a general equilibrium model. Empirically, I base my analysis on a panel of Swedish firms where data on collateral pledges are observable. Exploiting this unique information on collateral values across firms and over time, I estimate the heterogeneity in firm investment responses

[1] For business cycle facts, see Cooley and Prescott (1995).

conditional on the variation in collateral pledges to identified monetary policy shocks. Using local projections panel regression, I find that firms with relatively high collateral pledges, i.e. firms that pledge a relatively higher share of their total assets as collateral, are more responsive to monetary policy shocks. Quantitatively, these firms cumulatively *reduce* investments by 5 percentage points more than firms with low collateral pledges three years after a 22 basis points contractionary monetary policy shock. In addition, the elasticity of borrowing to monetary policy shocks is also stronger among firms with high collateral pledges – providing some evidence for collateral-based borrowing constraints. These empirical results are robust to alternative specifications.

Motivated by the heterogeneity in firm investment responses to monetary policy as a consequence of variation in collateral pledges found in the data, I develop a New Keynesian model with heterogeneous credit constrained firms. I calibrate the model to the Swedish economy. Consistent with the empirical results, I find that firms with high collateralizable capital are more responsive to monetary policy shocks in the model, and the responses are somewhat stronger. These results provide new insights and have policy implications in that (*i*) monetary policy is shown to more effective in stabilizing inflation in the presence of credit frictions and when firms' colleteral pledges are relatively high and (*ii*) credit frictions are more likely to alter the transmission of monetary policy to firms' investments through the collateral channel rather than the liquidity (cash flows) or leverage channel.

I contribute to the strand of literature that studies the macroeconomic implications of credit frictions in two ways. The first being an empirical contribution. Until this paper, the explicit role of collateral has been silent in the empirical literature on credit frictions since the degree to which firms' assets are collateralized are usually unobservable. Papers instead implicitly assume that firms' access to external debt financing is conditional on collateral and then use observables such as liquidity (Jeenas, 2019), leverage and default risk (Otonello and Winberry, 2020), age (Cloyne et al., 2018), size (Gerlter and Gilchrist, 1993) and debt covenants (Dreschel, 2023) as proxies for colleteral and credit frictions. However, with access to data on actual collateral values at the firm-level, I am able to directly and empirically explore the collateral channel of monetary policy transmission that has until now, been mostly reserved for numerical analysis (see Bernanke, Gertler, and Gilchrist, 1999; Kiyotaki and Moore, 1997; Carlstrom, Fuerst, and Paustian, 1997; Jermann and Quadrini, 2012). I additionally contribute to the literature by developing a macro model with credit frictions to study business cycle dynamics in a small open economy such as Sweden (Stockhammar and Österholm, 2016). Most papers in the literature have focused on developing models to match and explain business cycle fluctuations in large industrial economies such as the U.S. This leaves ample room for my contribution in studying a small open economy.

The paper is outlined as follows: Section 2 provides a literature review. Section 3 develops an identification strategy for monetary policy shocks and uses this to provide empirical evidence that firms' investment responses to monetary policy varies with collateral pledges. Section 4 develops a general equilibrium model with heterogeneous credit constrained firms to explain the evidence found in the micro-data. Section 5 discusses the validity and relevance of the study. Section 6 concludes.

2 Literature Review

The literature on the macroeconomic consequences of financial frictions has a long standing tradition. Fisher (1933) debt-theory of the Great Depression is perhaps one of the earliest papers to document this. On the quest to explain the Great Depression, Fisher (1933) found the deterioration of collateral values *or* net worth resulting from the rise in real interest rates to be a confounding factor in the credit and macroeconomic squeeze during the depression. In more recent times, papers including Bernanke, Gertler, and Gilchrist (1999), Kiyotaki and Moore (1997), Carlstrom, Fuerst, and Paustian (1997), Iacoviello (2005), and Jermann and Quadrini (2012) have gone on to incorporate collateral constraints in general equilibrium models to study its role in amplifying macroeconomic shocks. At the micro-level, Jeenas (2019), Otonello and Winberry (2020), Cloyne et al. (2018), Gerlter and Gilchrist (1993) and Dreschel (2023) use firm financial and non-financial positions as proxies for credit frictions to study the transmission of monetary policy. On another dimension, Khan and Thomas (2013) and Buera, Kaboski, and Shin

(2011) explore the role of collatarized borrowing in the misallocation of capital across firms and how this causes aggregate productivity, investment, and output losses. A selection of the aforementioned literature will be reviewed in detail in the subsequent paragraphs.

Bernanke, Gertler, and Gilchrist (1999) show how fluctuations in collateral values *or* net worth of borrowers propagate monetary policy shocks and affect investments. With the help of a heterogeneous firm dynamic model exhibiting a financial accelerator that captures endogenous developments in firms' collateral values and financing premiums, they find that credit (collateral) constraints operate as some form of multiplier to economic shocks. After a 25 basis point expansionary monetary policy shock, i.e. 0.25 percentage points decrease in nominal interest rates, Bernanke, Gertler, and Gilchrist (1999) find that the initial response to investment is twice as great and is over time more persistent when the financial accelerator is active and firms' external financing is constrained by collateral (net worth). With the financial accelerator active, a decline in interest rates exacerbates investment through the increase in asset prices which in turn increases collateral values and borrowing limits. The opposite holds when monetary policy is contractionary.

Parallel to Bernanke, Gertler, and Gilchrist (1999), Iacoviello (2005) develops a general equilibrium model with nominal debt of both households and firms tied to housing values. The study shows that housing prices decline after a contractionary monetary policy shock, which leads to less borrowing and investments in housing in both the household and firm sector of the economy. When collateral constraints are enforceable, Iacoviello (2005) finds that output falls by more than 0.5 percent following a contractionary monetary shock relative to when constraints are not enforced. In a similar spirit to Iacoviello (2005), Kiyotaki and Moore (1997) show the macroeconomic consequences when access to external financing is conditional on collateral. Through a general equilibrium model with land as an asset used for both production and collateral against borrowing, Kiyotaki and Moore (1997) show that a negative technology shock that reduces the price of land puts firms' and the economy in a vicious cycle. With a decrease in price of land, firms' net worth falls. This sudden decline in net worth means less borrowing and investment, which in turn dampens net worth in subsequent periods, and so on.

With a slightly different approach to modelling credit frictions, Carlstrom, Fuerst, and Paustian (1997) study monetary policy transmission in a setup where firms face agency costs when externally financing working capital. They show that monetary policy exacerbates credit market distortions created by agency costs and this leads to an inefficient production mix for firms.[2] These agency costs end up manifesting themselves in higher markups and output losses.

The strand of the literature focusing on empirical methods has put more emphasis on using financial and non-financial position of firms as proxies for credit frictions in which to study the transmission of monetary policy. For instance, Gerlter and Gilchrist (1993) examine bank lending to small and large U.S. manufacturing firms when monetary policy is tight. They find that after a contractionary monetary policy shock, bank lending to smaller firms declines while it surprisingly rises for larger firms. Moreover, they show that larger firms tend to borrow to smooth declining sales when monetary policy and economic conditions are tight while smaller firms do not. A possible explanation for the heterogeneity in bank lending across firms of varying sizes is that large firms have relatively greater collaterizable net worth compared to small firms hence, less credit risks and frictions.

Continuing on the topic of using credit risk and leverage as proxies for credit frictions, Otonello and Winberry (2020) find that investments of firms with relatively low default risk are more responsive to monetary policy shocks. Using a quarterly panel of publicly traded U.S. firms, they find that the semi-elasticity of investment responses to monetary policy is 1.1 times higher when a firm is one standard deviation further from default than the average firm in their sample. With the same dataset as Otonello and Winberry (2020), Jeenas (2019) studies the role of liquidity in the transmission of monetary policy to firm investments. The paper finds liquidity to be more prevalent in the transmission of monetary policy to investments compared to leverage, supporting a conclusion that

[2] For example, production is inefficient when firms use sub-optimal levels of capital and labor.

credit frictions are more likely to interact with monetary policy transmission to firm investments through working capital (cash flows) than balance-sheet (asset prices).

More recently, Dreschel (2023) explores the role of earnings based borrowing constraints in propagating macroeconomic fluctuations. Motivated by loan-level data containing information on debt covenants for a set of non-financial U.S. firms, Dreschel (2023) develops a general equilibrium model where firms access to credit and borrowing limits are conditional on earnings (cash flows). The paper finds that with earnings based constraints, firms face lower price rigidities and charge higher markups compared to when borrowing is constrained by collateral. This is because markups, i.e. price over marginal cost, directly feeds into a firm's earnings and as a result borrowing limits. With access to credit being conditional on earnings, firms will exhibit a flexible behavior in terms of pricing to loosen borrowing constraints. This has macro implications for monetary policy and price stability.

The literature discussed above covers the role played by credit frictions in propagating various macroeconomic shocks, mostly notably monetary policy shocks. I expand on this by being the first to provide empirical evidence on the role of collateral in propagating macroeconomic shocks, something that has been silent due to collateral pledges being unobserved in firm financial statements. However, with access to off-balance sheet items of a panel of non-financial Swedish firms, I empirically and through a macro model show that the variation in collateral pledges across firms and over time can amplify monetary policy shocks and have consequences for the effectiveness of monetary policy in stabilizing the macroeconomy.

3 Microdata Evidence

This section uses Swedish data to provide empirical evidence on the role of colleteral in the transmission of monetary policy to firms' investments. First, I identify monetary policy shocks of the Riksbank in subsection 3.1 before discussing the firm-level data in 3.2. I conclude the section in subsection 3.3 where I use a local projections panel regression to study the heterogeneity in firm investment responses to monetary policy conditional on collateral.

3.1 Monetary Policy Shocks

The extent to which monetary policy is exogenous is limited as markets form expectations with regards to current and future path of policy rates. The identification of monetary policy therefore entails decomposing changes in policy rates into an endogenous (expected) and exogenous (shock) component. The general framework for identification I use is event-based and it is the following:

$$\begin{aligned} \epsilon_t^m &= \Delta r_t - E_t\{\Delta r_t\} \\ &= r_t - E_t\{r_t\} - r_{t-1} + E_t\{r_{t-1}\} \\ &= r_t - E_t\{r_t\} \end{aligned} \tag{1}$$

where ϵ_t^m is the monetary policy shock from the central bank's monetary policy announcement at time t, Δr_t is the change in the policy rate announced and $E_t\{\Delta r_t\}$ is the expected change in the policy rate by market participants.

Econometrically, I use high-frequency price movements of Swedish interest rate swaps around the Riksbank's monetary policy announcements combined with the event-study approach used in Krueger and Kuttner (1996), Gertler and Karadi (2015) and Jarociński and Karadi (2020) to determine monetary policy shocks. Krueger and Kuttner (1996) suggests that under the assumption of market efficiency in that prices incorporate available information, the observed price changes in policy rate-indexed derivatives around monetary policy announcements can serve as a proxy for unexpected changes in policy rates by market participants. In this spirit, I exploit the price changes in 30-day Stina contracts within a 24-hour window around the Riksbank's monetary policy announcements to identify monetary policy shocks.[3] The 30-day Stina contracts are interest rate swaps with the Sibor T/N rate as the underlying instrument on the floating leg. Stibor T/N is a tommorrow-next interbank lending rate in Sweden and it is very close to the Riksbank policy rate, commanding an average (fixed) premium of 10 basis points (see

[3] For e.g., Gürkaynak, Sack, and Swanson (2005) use 30-minutes, 1-hour and 24-hour windows in estimating monetary policy shocks of the Federal Reserve. The measures are qualitatively the same across time windows.

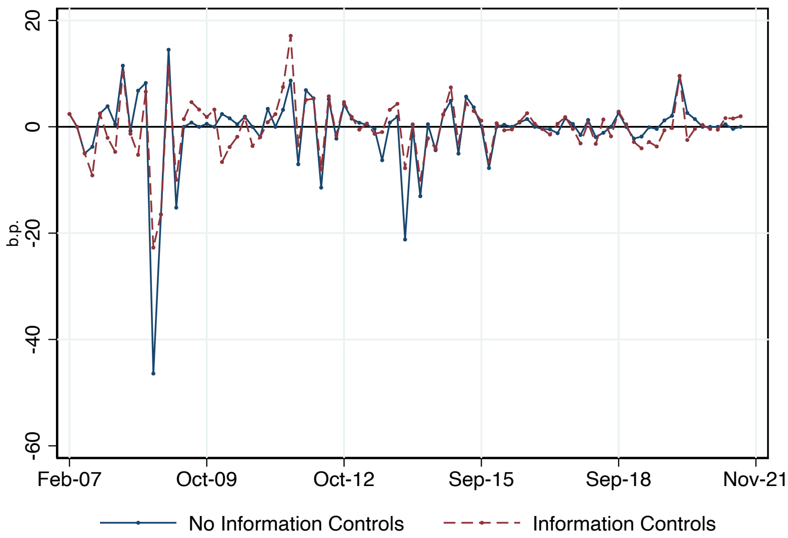
Åhl, 2017, and Ikonen and Njie, 2022). Figure A.1 plots the policy rate and Stina rate.

The monetary policy shocks from each monetary policy announcement made by the Riksbank are constructed following Åhl (2017):

$$\epsilon_t^m = \frac{\tau}{30}(r_t^{STINA} - r_{t-1}^{STINA}) \tag{2}$$

where τ[4] is the remaining days-to-maturity of the 30-day Stina contract after the announced policy rate is the implemented, r_t^{STINA} and r_{t-1}^{STINA} are the closing price of the 30-day Stina contract on the day of announcement and the day prior respectively. I use the shocks constructed from (2) as my baseline measure for monetary policy shocks in the empirical analysis.

Figure 1: Monetary Policy Shocks



Notes: The figure shows the high-frequency monetary policy shocks from each Riksbank monetary policy announcement from 2007 to 2021. The time series *No Information Controls* are shocks constructed from (2), i.e. $\{\epsilon_t^m\}$, and *Information Controls* are shocks from (3), i.e. $\{\overline{\epsilon_t^m}\}$. Each dot represents a monetary policy announcement. The units in the y-axis are in basis points

In conjunction with announcing the policy rate, the Riksbank releases its own economic

[4] The term $\frac{\tau}{30}$ accounts for the lag between monetary policy announcement and implementation. In general, the policy rate implemented the following Wednesday after its announcement.

forecasts for the policy rate, GDP and inflation during monetary policy announcements. The monetary policy shocks identified using equation (2) are therefore not completely exogenous to the central bank's and market participants' concerns about both current and future states of the economy. I remedy this problem by constructing an alternative monetary policy shock that controls for the Riksbank's information channel. Following normative approaches by Miranda-Agrippino and Giovanni (2021) and Romer and Romer (2004), this alternative monetary policy shock is the residual $\overline{\epsilon_t^m}$ from the following regression

$$\epsilon_t^m = \sum_{i=0}^{2}(\mu_i r_{it} + \mu_i^{\Delta}\Delta r_{it}) + \sum_{i=0}^{2}(\gamma_i y_{it} + \gamma_i^{\Delta}\Delta y_{it}) + \sum_{i=0}^{2}(\lambda_i \pi_{it} + \lambda_i^{\Delta}\Delta\pi_{it}) + \overline{\epsilon_t^m} \tag{3}$$

where r_{it}, y_{it} and π_{it} are policy rate, GDP and inflation i periods-ahead (years) forecasts released at the monetary policy announcement; Δr_{it}, Δy_{it} and $\Delta\pi_{it}$ are forecast revisions between the monetary policy announcement at time t and $t-1$. γ_i, γ_i^{Δ},μ_i, μ_i^{Δ}, π_i, π_i^{Δ} are coefficients. The purpose of (3) is to obtain $\overline{\epsilon_t^m}$, which is interpreted as the monetary policy shock after controlling for central bank information. The coefficients from (3) are off no analytical interest in the context of this paper, but nevertheless provided in Table A.2.

Table 1: Summary Statistics of Monetary Policy Shocks

	No Information Controls		Information Controls	
	High Frequency	Aggregate	High Frequency	Aggregate
Mean	-0.75	-4.76	-0.25	-1.46
Std. Dev.	7.52	22.18	5.55	12.95
P25	-1.12	-3.33	-2.85	-6.40
P50	0.00	0.50	0.00	0.40
P75	2.07	16.50	5.29	22.30
Observations	91	169	91	169

Notes: The table presents summary statistics for constructed monetary policy shocks. Column (1) and (2) provides statistics for shocks constructed in (2) and Column (3) and (4) provides statistics for shocks constructed in (3). The units are in basis points

The monetary policy shocks are constructed for each monetary policy announcement between 2007 and 2021. The Riksbank had a total of 91 announcements during this time period and the shocks from each announcement are plotted in Figure 1. To merge the shocks with the annual firm-level data for the analysis in subsection 3.3, I aggregate them at annual frequency using a 12-month rolling sum. I do this because the financial year of firms vary across months over the calendar year in the data. Table 1 presents an overview of the high-frequency and 12-month rolling aggregate monetary policy shocks.

3.2 Firm Data

I use consolidated financial statement, off-balance sheet and non-financial firm-level data from the Serrano Database, an annual panel covering Swedish firms since 1997. Serrano combines financial statement and bankruptcy data from the Swedish Companies Registration Office (*Sw:* Bolagsverket), general firm data from Statistics Sweden and data on corporate structures from Bisnode into a comprehensive dataset. It is maintained by the Swedish House of Finance and updated bi-annually (Weidenman, 2016).

The sample period I use is 2007 to 2021. I start in 2007 because this was the earliest period I could construct monetary policy shocks.[5] In addition, a set of sampling restrictions were applied to the data to improve precision in measurement and inference. First, I remove all firm-year observations with reporting period less than 12 months. Subsequently, I exclude financial, real estate and utility firms due to the unique characteristics of their balance sheets. Third, firms that are less than two years old or have missing age data were excluded. I additionally exclude firms with less than two employees or missing employee data. Non-limited liability companies are also excluded to account for legal corporate structure which is important in terms of external financing. Firms that are owned by the state, a county or a municipality were excluded to limit the unit of analysis to private sector firms. In addition, I exclude firms that are registered but inactive. Firms undergoing mergers, restructuring, bankruptcy or liquidation are also excluded as these firms are no longer going-concerns. Lastly, I exclude firms with missing or negative sales, assets, equity and information on collateral values. The final sample consists of 37,122 observations and 7,654 unique firms. The median firm age and number of employees in the sample are 18 and 61 respectively. Table A.1 provides a comprehensive view of the sampling restrictions applied.

[5] The 30-day Stina contracts were introduced by Nasdaq Stockholm in 2007.

The firm-level variables of interest in the empirical analysis are collateral, investments, borrowing, leverage, liquidity, total assets, sales growth, number of employees and age. Investments are defined as the net-change in capital stock $\log(K_{it}) - \log(K_{it-1})$ where K_{it} is the value of property, plant and equipment for firm i and time t. Borrowing is the net-change in debt and similarly defined as $\log(B_{it}) - \log(B_{it-1})$ where B_{it} is total short-term and long-term debt. Sales growth is defined as $\log(Y_{it}) - \log(Y_{it-1})$ where Y_{it} is total sales. Collateral is the ratio of pledged assets to total assets. Leverage is the ratio of total debt to total assets, and liquidity is the ratio of liquid financial assets i.e cash and cash equivalents, to total assets. A firm's age is constructed by subtracting the panel year from the year it starts to become *active*. Serrano defines a firm's initial *active* year as the year it either registers for corporate taxes or VAT or as an employer. I deflate all financial variables to real-terms with 2016 as the base.

Table 2: Summary Statistics of Firm Data

	Mean	Std. Dev.	P25	P50	P75	Observations
Investments	0.014	0.479	-0.144	-0.033	0.127	28,604
Borrowing	-0.016	0.807	-0.232	-0.041	0.193	19,292
Collateral	0.349	0.286	0.096	0.300	0.548	37,122
Liquidity	0.153	0.159	0.031	0.100	0.224	37,122
Leverage	0.167	0.186	0.000	0.107	0.282	37,122
Total Assets	18.433	1.411	17.526	18.277	19.204	37,122
Sales Growth	0.038	0.267	-0.063	0.033	0.140	37,122

Notes: The table presents summary statistics of firm-level variables. Collateral is truncated at 1 to make sure firms do not pledge more than 100 percent of total assets as collateral. Investment, Sales Growth and Total Assets are winsorized at the 1 and 99 percentiles to exclude outliers. Total Assets are in logs.

Table 2 presents summary statistics for the firm-level variables. It shows a major dispersion in collateral pledges across firms in the data with the lower and upper 25 percent of firms pledging around 10% and 55% of total assets as collateral respectively. Compared to leverage and liquidity which are traditionally used as proxies for credit frictions as in Jeenas (2019) and Otonello and Winberry (2020), collateral has a much higher variation judging from its standard deviation. The purpose of the subsequent exercise is to investigate whether this variation in collateral pledges can explain heterogeneity in firm investment responses to monetary policy.

3.3 Firm Investment Responses to Monetary Policy

Specification The purpose of this section is to estimate how firms' cumulative investment $\log(K_{it+h}) - \log(K_{it})$ over a horizon $h = 1, 2 \ldots 5$ responses to monetary policy shocks ϵ_t^m are conditional on collateral. This is done by estimating a panel local projections regression over a 5 year horizon h following the method by Jordà (2005) and a specification similar to Jeenas (2019). The baseline specification is

$$\log(K_{it+h}) - \log(K_{it}) = \alpha_i + \alpha_{st} + \beta^h(\nu_{it} \times \epsilon_t^m) + (\Phi' + \Gamma'\epsilon_t^m)F_{it} + \Upsilon' Z_{it} + e_{it+h} \quad (4)$$

where time t is reporting year-month, α_i are firm fixed effects, α_{st} are time-sector fixed effects where sector is 2-digit SNI code, ν_{it} is collateral of firm i at time t, and ϵ_t^m is the aggregated monetary policy shock at time t (see Section 3.1) scaled by its standard deviation for interpretability. F_{it} is a vector of firm financial position controls – leverage and liquidity; Z_{it} is a vector of firm non-financial controls – total assets, size (num. of employees) and sales growth. The impulse responses that show the differences in firm investment responses to monetary policy conditional on the variation in collateral are $\{\beta^h\}_{h=1}^5$. Υ and Φ are coefficient vectors of the firm financial and non-financial positions respectively. Γ is a coefficient vector of interactions between firm financial position controls and monetary policy shocks, and e_{it+h} is the error term. The specification in (4) has great flexibility in that it allows for the control of firm financial position other than collateral while also exploring their possible monetary policy transmission channels.

Although the monetary policy shocks are exogenous by construction, firm covariates are added in (4) to ensure the exogeniety of colleteral. I add firm fixed effects to control for overall heterogeneous firm characteristics that impact both collateral and investments. In addition, I control for firm size and growth as these has been shown to impact investment dynamics of firms (see Cloyne et al., 2018 and Gerlter and Gilchrist, 1993). For instance, small and fast growing companies display a tendency to expand capital stock faster as they are further away from their optimal level of capital. Financial positions such as liquidity and leverage are controlled for as these are also possible monetary policy transmission channels as shown in Otonello and Winberry (2020) and Jeenas (2019). Time-sector fixed effects are added to control for sector specific as well as macroeconomic developments over-time. In addition, I cluster the standard errors at firm-level and reporting month-sector level to account for serial correlation within firms and sectors. I choose to cluster by month-sector due to seasonality as Teterukovsky (2008) found reporting of investment plans from a set of Swedish firms to exhibit seasonal behavior.

Results Table 3 shows the differential in firm investment responses 1-year after a contractionary monetary policy shock. Column (1) indicates that 1-year following a 1-standard deviation, i.e. 22 basis points monetary policy shock, firms that pledge all their total assets as collateral reduce investments by 2.3 percentage points more than firms with no collateral. This estimate is both statistically and economically significant.

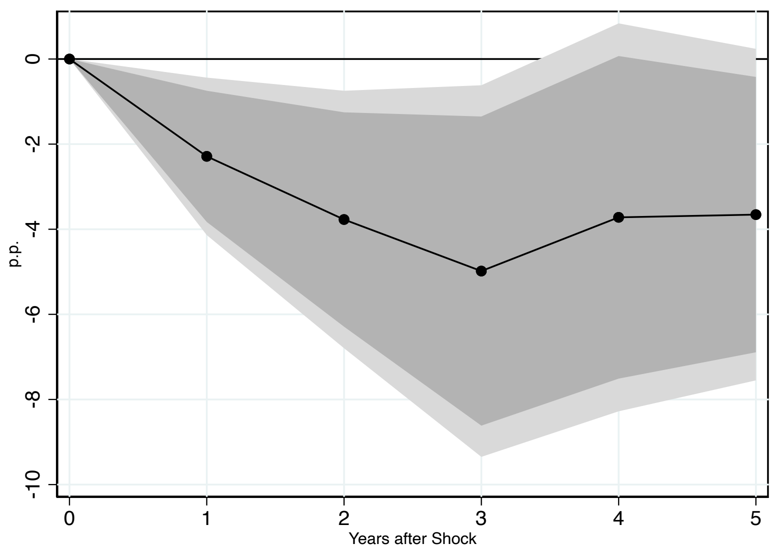
Table 3: Firm Investments Responses 1-year after a Monetary Policy Shock

	(1)	(2)	(3)
Collateral $\times$ ϵ_t^m	-0.023**	-0.033***	-0.031***
	(0.009)	(0.012)	(0.008)
Liquidity $\times$ ϵ_t^m		-0.047**	
		(0.024)	
Leverage $\times$ ϵ_t^m		-0.003	
		(0.021)	
ϵ_t^m			0.022***
			(0.005)
Firm controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Time sector FE	Yes	Yes	No
R^2	0.273	0.273	0.211
Observations	25,889	25,889	26,668

Notes: The table reports estimates of heterogenous firm investment responses 1-year, i.e. $h = 1$, after a monetary policy shock. The monetary policy shock ϵ_t^m is scaled by its standard deviation of around 22 basis points for convenience in terms of interpretation. Firm controls include liquidity, leverage, total assets, employees and sales growth. Time-sector fixed effects are by year-month and 2-digit SNI code. Singletons are excluded from estimation. Standard errors, two-way clustered by firm and 2-digit sector code-reporting month, in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

By allowing monetary policy shocks to transmit through liquidity and leverage in Column (2), the estimate for collateral increases to 3.3 percentage points and still remains significant. Column (2) additionally shows liquidity to be a significant channel for transmission of monetary policy to investment but not leverage, consistent with the findings in Jeenas (2019). Column (3) removes the time-sector fixed effects to estimate the average effect of monetary policy shocks on firm investments. The results indicate that 1-year after a 22 basis points monetary policy shock, firms' investments in average increase by 2.2 percentage points in the absence of collateral. In the presence of collateral, investments are shown to decrease.

Figure 2: Heterogeneity in Firm Investment Responses to Monetary Policy Shocks



Notes: The figure shows impulse responses of the interaction coeffecients between collateral and monetary policy shocks $\{\beta^h\}_{h=1}^5$ over time. The coeffecients are estimated from a specification of (4) where monetary policy shock only transmit through collateral and $\Gamma = \mathbf{0}$. The dark (light) grey area is the 90% (95%) confidence intervals based on two-way clustered standard errors by firm and month-sector.

Figure 2 shows heterogeneity in firm investment dynamics as a result of collateral following a monetary policy shock. The impulse responses $\{\beta^h\}_{h=1}^5$ are estimated from the local projections in (4) where I exclude Γ to independently investigate the role of collateral in monetary policy transmission to investment. The impulse response show that 3-years following a 1-standard deviation monetary policy shock, firms with relatively high collateral cumulatively reduce investments by 5 percentage points more than firms with no collateral. This reduction is also persistent over time.

The results presented in Table 3 and Figure 2 are robust to an alternative specification where I control for the Riksbank's economic forecasts in the construction of monetary policy shocks as done in (3). The estimates for collateral are qualitatively the same but quantitatively marginally smaller when controlling for economic forecasts and using $\overline{\epsilon_t^m}$ instead of ϵ_t^m as measure of monetary policy shocks. Table 4 presents estimates for firm investment responses 1-year following a 1-standard contractionary monetary policy shock when controlling for central bank information.

Table 4: Controlling for Central Bank Economic Forecasts

	(1)	(2)	(3)
Collateral × $\overline{\epsilon_t^m}$	-0.019**	-0.032**	-0.020**
	(0.009)	(0.013)	(0.008)
Liquidity × $\overline{\epsilon_t^m}$		-0.028	
		(0.026)	
Leverage × $\overline{\epsilon_t^m}$		0.014	
		(0.019)	
$\overline{\epsilon_t^m}$			0.013**
			(0.005)
Firm controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Time sector FE	Yes	Yes	No
R^2	0.273	0.273	0.196
Observations	25,889	25,889	26,668

Notes: The table reports estimates of heterogenous firm investment responses 1-year, i.e. $h = 1$, after a monetary policy shock. The monetary policy shock $\overline{\epsilon_t^m}$ controls for the Riksbanks's economic forecast as shown in 3. It scaled by its standard deviation of around 12.95 basis points for convenience in terms of interpretation. Firm controls include liquidity, leverage, total assets, employees and sales growth. Time-sector fixed effects are by year-month and 2-digit SNI code. Singletons are excluded from estimation. Standard errors, two-way clustered by firm and 2-digit sector code-reporting month, in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Interestingly, both liquidity and leverage are insignificant in explaining heterogeneous investment responses to monetary policy shocks when controlling for central bank economic forecast. However, collateral is still significant. This result counters both Jeenas

(2019) and Otonello and Winberry (2020) and shows collateral to be the predominant source of financial friction in the transmission of monetary policy to investments. In hindsight, credit frictions should manifest themselves as collateral since this is usually the basis on which most lenders, especially banks, lend to firms.

Table 5: Controlling for Policy Regimes

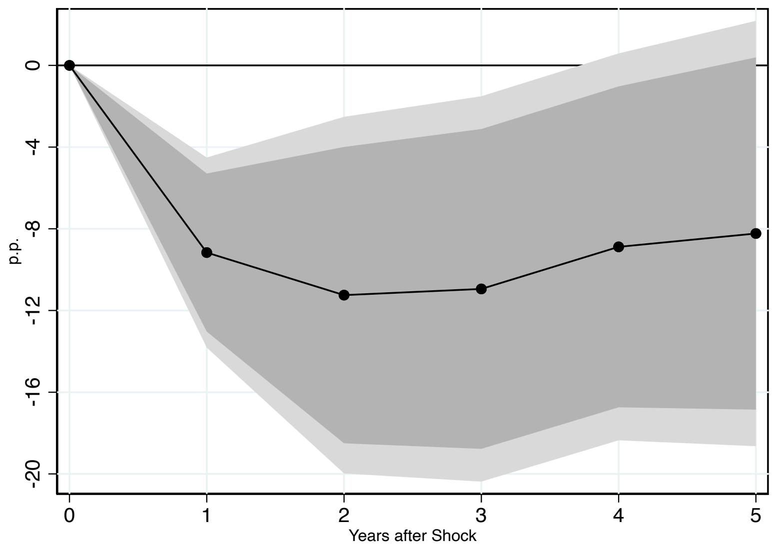
	(1)	(2)	(3)	(4)	(5)	(6)
	Pre- Zero Lower Bound			Post- Zero Lower Bound		
Collateral × ϵ_t^m	-0.025***	-0.027**	-0.030***	-0.058	-0.096*	-0.058
	(0.008)	(0.011)	(0.008)	(0.043)	(0.054)	(0.043)
Liquidity × ϵ_t^m		-0.031			-0.153**	
		(0.026)			(0.068)	
Leverage × ϵ_t^m		-0.013			0.006	
		(0.023)			(0.053)	
ϵ_t^m			0.026***			0.000
			(0.004)			(0.000)
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Time sector FE	Yes	Yes	No	Yes	Yes	No
R^2	0.348	0.348	0.289	0.324	0.324	0.324
Observations	14,214	14,214	14,570	11,212	11,212	11,212

Notes: The table reports estimates of heterogenous firm investment responses 1-year, i.e. $h = 1$, after a monetary policy shock pre- and post-ZLB periods. The pre-ZLB periods is before 2014 and post-ZLB is 2014 to 2021. The monetary policy shock ϵ_t^m is scaled by its standard deviation of around 22 basis points for convenience in terms of interpretation. Firm controls include liquidity, leverage, total assets, employees and sales growth. Time-sector fixed effects are by year-month and 2-digit SNI code. Singletons are excluded from estimation. Standard errors, two-way clustered by firm and 2-digit sector code-reporting month, in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

The empirical analysis is extended to study the interaction of collateral and monetary policy on firms' investments pre and during Zero Lower Bound (ZLB) periods on policy rates. The Riksbank policy rate was effectively set to zero in October 2014 (Riksbank, 2015) and shortly after, the central bank implemented its first quantitative easing program and placed the policy rate in negative territory. I perform additional analysis by splitting the sample into pre- and post-ZLB to account for the role of changing policy regimes. Expectedly, Table 5 shows that the original results are robust to the pre-ZLB period when the policy rate was effectively used to conduct monetary policy. During periods of unconventional monetary policy, i.e. post-ZLB, both the average and differential (on collateral) impact of monetary policy on investment disappears. This is expected as the policy rate which the monetary policy shocks are based on become practically ineffective post-ZLB. The results also show liquidity to be very a prevalent channel of monetary policy to firms investment post-ZLB, but exploring the liquidity channel is beyond the scope of this paper. These results are very relevant to the current state of the world as central banks have yet again begun using policy rates as a main tool in conducting monetary policy.

The Role of Borrowing A contractionary monetary policy is posited to decrease collateral values and hence, borrowing of firms. The reduction in borrowing then contracts investments. I empirically explore the role of collateral in borrowing by using the same specification in (4) but with borrowing $\log(B_{it}) - \log(B_{it-1})$ as the outcome vari

Figure 3: Heterogeneity in Firm Borrowing Responses to Monetary Policy Shocks



Notes: The figure shows impulse responses of the interaction coefficients between collateral and monetary policy shocks $\{\beta^h\}_{h=1}^5$. The coeffecients are estimated from a specification of (4) where borrowing $\log(B_{it+h}) - \log(B_{it})$ is the outcome variable and $\Gamma = \mathbf{0}$. The dark (light) grey area is the 90% (95%) confidence intervals based on two-way clustered standard errors by firm and month-sector.

-able and excluding Γ as a vector of explanatory variables. Figure 3 shows that 3-years following a 1-standard deviation monetary policy shock, firms that pledge all their assets as collateral cumulatively reduce borrowing by around 12 percentage points more than firms with no collateral. The magnitude of the borrowing response is twice as much as investments. This result indicates that (i) firms face collateral-based borrowing constraints and (ii) when monetary policy is contractionary and collateral values fall, firms that have already pledged a high share of their assets as collateral are more affected as they have no more assets to pledge to increase borrowing.

The main takeway from the empirical exercise is that the impact of monetary policy on firms' investments strongly varies with collateral. Compared to alternative channels of credit frictions such as leverage and liquidity, variation in collateral is shown to generate stronger heterogeneity in firm investment responses to monetary policy shocks. This indicates that colleteral is the primary source of credit friction that amplifies the transmission of monetary policy to firms' investments.

The subsequent section develops a general equilibrium model with heterogeneous credit constrained firms to reconcile the evidence found in the microdata and show the macroeconomic consequences of monetary policy in the presence of collateral constraints.

4 Model

The model is a New Keynesian DSGE model with both nominal wage and price rigidities à la Erceg, Henderson, and Levin (2000) and Rotemberg (1982) respectively. The economy contains a continuum of infinitely lived households $l \in (0, 1)$ with each household supplying a specialized labor service l to firms. There is a representative final good producer and continuum of intermediate good firms $i \in (0, 1)$ in monopolistic competition. Henceforth, I refer to the intermediate good firms simply as firms. Two sets of firms $\{\mathcal{H}, \mathcal{L}\}$ are present and firms belonging to each set have identical collateralizable capital and behave the same in equilibrium. Let $\mathcal{S}$ denote the entire set of firms. Firms $i \in \mathcal{H} \subseteq \mathcal{S}$ have mass τ and have high collateralizable capital while firms $i \in \mathcal{L} \subseteq \mathcal{S}$ have mass $1 - \tau$ and low collateralizable capital. Firms $\mathcal{H}$ can be likened to firms that are highly dependent on colleteral for borrowing and those with high collateral pledges in the data.

Conversely for firms $\mathcal{L}$. I conclude the model by adding a central bank responsible for monetary policy in the economy.

The economy has three markets: a goods market, a labor market and a credit (bond) market. Lending and borrowing between households and firms occurs in the bond market and I assume that bond contracts are intermediated by a financial institution for convenience. The economy faces three exogenous shocks: a monetary policy shock, a technology shock and a risk premium shock. The risk premium creates a wedge between the central bank policy rate and firms' financing rate and it is modelled following Smets and Wouters (2007).

The model design is inspired by the canonical New Keynesian frameworks in Gali (2015) and Sims (2007). However, I add collateral constraints to account for the dynamics I find in the micro data.

4.1 Households

Preferences The economy is populated by heterogeneous households indexed by their labor type $l \epsilon (0, 1)$ who have additive separable constant relative risk aversion utility $U[C_t(l), N_t(l)]$ over consumption $C_t(l)$ and employment $N_t(l)$.[6] The household utility U is continuous, twice differentiable, with $U_{c,t} > 0$, $U_{cc,t} \leq 0$, $U_{n,t} < 0$ and $U_{nn,t} \leq 0$.[7] I keep utility separable so that households in equilibrium will have identical consumption and bond holding, but vary in wages and labor supply (see Erceg, Henderson, and Levin, 2000). Therefore, I henceforth remove the index l on consumption.

At each period t, households choose quantities of consumption C_t, labor $N_t(l)$ and investments in a one-period corporate bonds B_t with face value of 1 to maximize expected lifetime utility. The household problem is

$$\max_{C_t, N_t(l), B_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \zeta \frac{N_t(l)^{1+\eta}}{1+\eta} \right) \tag{5}$$

[6] I follow the notational convention in Blanchard and Gali (2010) and interpret $N_t = \int_0^1 N_t(l)dl$ as the fraction of households employed – the employment rate.

[7] The terms $U_{c,t}$ ($U_{n,t}$) and $U_{cc,t}$ ($U_{nn,t}$) are first and second derivatives of consumption (labor) respectively.

subject to a sequence of budget and labor demand constraints

$$P_tC_t + B_t \leq W_t(l)N_t(l) + (1 + \lambda_{t-1}r_{t-1})B_{t-1} + \Xi_t \tag{6}$$

$$N_t(l) = \left(\frac{W_t(l)}{W_t}\right)^{-\epsilon_w} N_t \tag{7}$$

and a no-Ponzi game ("solvency constraint") condition[8]

$$\lim_{T\to\infty} E_0 \left\{\Lambda_{t,T}\frac{B_T}{P_T}\right\} \geq 0 \tag{8}$$

where the stochastic discount factor or pricing kernel is

$$\Lambda_{t,t+k} \equiv \beta^k E_t \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \tag{9}$$

and $0 < \beta < 1$ is the discount rate, $\sigma > 0$ is the relative risk aversion, $\eta > 0$ is inverse of the Frisch elasticity, $\zeta > 0$ scales disutility from labor. Ξ_t are sum of real profits from firms distributed to the household, r_t is the nominal interest rate on the one period zero coupon corporate bond and $\log(\lambda_t) = \rho_\lambda \log(\lambda_{t-1}) + u_t^\lambda$, $u_t^\lambda \sim \mathcal{N}(0, \sigma_\lambda)$ is the exogenous risk premium. The risk premium is a wedge between the central bank controlled nominal interest rate r and the borrowing (lending) rate from the corporate (household) sector added to create exogenous volatility in credit spreads. $C_t \equiv \left(\int_0^1 C_t(i)^{\frac{\epsilon_p-1}{\epsilon_p}} di\right)^{\frac{\epsilon_p}{\epsilon_p-1}}$ is a Dixit and Stiglitz (1997) consumption aggregate of a continuum of differentiated goods produced by firms $i \ \epsilon \ (0,1)$, $P_t \equiv \left[\int_0^1 P_t(i)^{1-\epsilon_p} di\right]^{\frac{1}{1-\epsilon_p}}$ is the aggregate price index, $C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon_p} C_t$ is the downward slopping demand curve for the good produced by firm i, $\epsilon_p > 1$ measures the degree of substitutability between good i and i_{-1}. The derivations for the demand function $C_t(i)$ and price index P_t are a result of solving a cost-minimization problem for the household where total expenditures on goods $\int_0^1 P_t(i)C_t(i)di$ are minimized subject to C_t. The labor demand constraint (7), the aggregate wage index W_t and total employment N_t is a result of firms minimizing their total wage bill and presented further in (20).

[8] The boundary solution for the no-Ponzi game condition is the transversality condition.

Labor Market Each household provides a differentiated labor type $l \in (0,1)$ in a monopolistic competitive labor market to firms. This market structure gives households some market power with respect to wages charged for their labor. In the economy, households are able to renegotiate for a *new* wage $W_t^\star(l)$ at each time period t with probability $1-\omega$, and with probability ω^k continue charging the same wage for $t+k$ periods.

Let $w_t(l)^\star = \frac{W_t^\star(l)}{P_t}$ and $w_{t+k}^\star(l) = \frac{W_t^\star(l)}{P_t}\frac{P_t}{P_{t+k}} = w_t^\star(l)\Pi_{t,t+k}^{-1}$ denote the real renegotiated wage at time t and $t+k$ respectively, with $\Pi_{t,t+k} \equiv \frac{P_{t+k}}{P_t}$ defined as the gross inflation rate between $t+k$ and t. Similarly, define $w_t = \frac{W_t}{P_t}$ as the real aggregate wage index. The household negotiates by choosing $w_t^\star(l)$ to maximize the sum of discounted utilities over the $t+k$ time period during which $w_t^\star(l)$ remains unchanged. The household problem with respect to wage setting is

$$\max_{w_t^\star(l)} \quad E_t \sum_{k=0}^{\infty}(\beta\omega)^k \left[\frac{C_{t+k}^{1-\sigma}}{1-\sigma} - \zeta\frac{\left(\frac{w_t(l)^\star\Pi_{t,t+k}^{-1}}{w_{t+k}}\right)^{-\epsilon_w(1+\eta)} N_{t+k}^{1+\eta}}{1+\eta}\right] \tag{10}$$

subject to a sequence of *real*[9] budget (6) and labor demand (7) constraints with real wages $w_t(l)$ replaced with the real renegotiated wage $w_t^\star(l)$. The households still face the same problem as in (5), but now additionally discounts the future with the probability ω of being stuck at the same wage, and chooses $w_t^\star(l)$ rather than $N_t(l)$ as labor demand (7) for the skill type l of the household is predetermined by integrating (20) over all firms i.

Dynamic Problem The household decision for wage choices are independent of consumption and bond holding decisions as preferences are additive separable. At each period t, the households solve (5) by choosing B_t and C_t and solves (10) by choosing $w_t^\star(l)$. Household behavior is characterised by the following first order conditions

$$C_t^{-\sigma} = \beta E_t\left\{C_{t+1}^{-\sigma}\Pi_{t+1}^{-1}\right\}(1+\lambda_t r_t) \tag{11}$$

[9]The budget constraint (6) is converted to real terms by dividing with P_t

$$w_t(l)^{\star,1+\epsilon_w\eta} = \frac{\epsilon_w}{\epsilon_w - 1}\frac{S_{1,t}}{S_{2,t}} \tag{12}$$

where $\Pi_{t+1} \equiv \frac{P_{t+1}}{P_t}$ is the gross inflation rate at time $t+1$ and,

$$\begin{aligned} S_{1,t} &= E_t \sum_{k=0}^{\infty} (\beta\omega)^k \zeta w_{t+k}^{\epsilon_w(1+\eta)} N_{t+k}^{1+\eta} \Pi_{t,t+k}^{\epsilon_w(1+\eta)} \\ &= \zeta w_t^{\epsilon_w(1+\eta)} N_t^{1+\eta} + E_t \sum_{k=0}^{\infty} (\beta\omega)^{k+1} w_{t+k+1}^{\epsilon_w(1+\eta)} N_{t+k+1}^{1+\eta} \left(\frac{P_{t+k+1}}{P_{t+1}}\frac{P_{t+1}}{P_t}\right)^{\epsilon_w(1+\eta)} \\ &= \zeta w_t^{\epsilon_w(1+\eta)} N_t^{1+\eta} + \beta\omega E_t\{\Pi_{t+1}^{\epsilon_w(1+\eta)} S_{1,t+1}\} \end{aligned} \tag{13}$$

$$\begin{aligned} S_{2,t} &= E_t \sum_{k=0}^{\infty} (\beta\omega)^k C_{t+k}^{-\sigma} w_{t+k}^{\epsilon_w} N_{t+k} \Pi_{t,t+k}^{\epsilon_w - 1} \\ &= C_t^{-\sigma} w_t^{\epsilon_w} N_t + E_t \sum_{k=0}^{\infty} (\beta\omega)^{k+1} C_{t+k+1}^{-\sigma} w_{t+k+1}^{\epsilon_w} N_{t+k+1} \left(\frac{P_{t+k+1}}{P_{t+1}}\frac{P_{t+1}}{P_t}\right)^{\epsilon_w - 1} \\ &= C_t^{-\sigma} w_t^{\epsilon_w} N_t + \beta\omega E_t\{\Pi_{t+1}^{\epsilon_w - 1} S_{2,t+1}\} \end{aligned} \tag{14}$$

The first equation characterizing household behavior (11) is the consumption Euler equation. It shows that bond holding decisions are governed by the marginal rate of substitution between consumption at time t and $t+1$, the discount rate and expected inflation. In short, the current bond price 1 is the inflation adjusted expected payoff at time $t+1$ discounted by the pricing kernel.

The second equation (12) is the optimal wage setting. Interestingly, it shows that all households renegotiating for a *new* wage at time t will choose the same wage regardless of labor variety l. This is because the right hand side of equation is not conditional on l. Therefore, I remove the index l from the newly negotiated wage $w_t^\star$ henceforth. In the absence of wage rigidities $\omega = 0$ and presence of perfectly competitive labor market $\epsilon_w \to \infty$, (12) becomes

$$\zeta \frac{N_t^\eta}{C_t^{-\sigma}} = w_t \tag{15}$$

which shows that the real wage equates marginal rate of substitution between labor and consumption.

In summary, the optimal behavior of households in the economy is characterized by the Euler equation (11), optimal wage setting (12), the budget constraint (6) and the no-Ponzi game condition (8).

4.2 Firms

Final Goods Producer The representative final good producer assembles intermediate goods $Y_t(i)$ produced by firms into an aggregate output good Y_t following a Dixit and Stiglitz (1997) aggregation technology

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon_p - 1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p - 1}} \tag{16}$$

The final good producer's problem is to minimize expenditures $\int_0^1 P_t(i) Y_t(i) di$ over the set of intermediate goods $i \, \epsilon \, (0, 1)$ subject to (16). The solution to this problem yields the i^{th} firm's demand curve

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_p} Y_t \tag{17}$$

where $P_t(i)$ is the price charged by firm i, $P_t \equiv \left[\int_0^1 P_t(i)^{1-\epsilon_p} di \right]^{\frac{1}{1-\epsilon_p}}$ is the aggregate price index and $\epsilon_p > 1$ is the degree of substitution between goods i and i_{-1}. Each firm's demand curve (17) is downward slopping and combing this with a constant returns to scale production function creates an additional dimension to which firms are heterogeneous in the model. This form of market structure is common in the heterogeneous firm literature (see Melitz, 2003 and Hsieh and Klenow, 2009),

Production The economy is populated by a continuum of firms $i \, \epsilon \, (0, 1)$ in monopolistic competition with each firm producing a differentiated good $Y_t(i)$ using a constant returns to scale Cobb-Douglas production technology

$$Y_t(i) = A_t K_t(i)^{\alpha} N_t(i)^{1-\alpha}, \tag{18}$$

where α is capital share in production, $K_t(i)$ is capital and $N_t(i)$ is a labor input index, and $\log(A_t) = \rho_a \log(A_{t-1}) + u_t^a$, $u_t^a \sim \mathcal{N}(0, \sigma_a)$ is a Markovian stochastic exogenous technological process common to all firms.

Labor Each firm's labor input $N_t(i)$ is an aggregate of differentiated labor units $l \, \epsilon \, (0,1)$ provided by households

$$N_t(i) = \left(\int_0^1 N_t(i,l)^{\frac{\epsilon_w - 1}{\epsilon_w}} dl \right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{19}$$

where $N_t(i,l)$ is the quantity of labor variety l employed by firm i and $\epsilon_w > 1$ is the elasticity of substitution between labor varieties. Each firm chooses $N_t(i,l)$ by minimization its total wage bill $\int_0^1 W_t(l) N_t(i,l) dl$ subject to (19). The solution to this problem yields the i^{th} firm's demand schedule for each labor variety l

$$N_t(i,l) = \left(\frac{W_t(l)}{W_t} \right)^{-\epsilon_w} N_t(i) \tag{20}$$

where

$$W_t = \left(\int_0^1 W_t(l)^{1-\epsilon_w} dl \right)^{\frac{1}{1-\epsilon_w}} \tag{21}$$

is the aggregate wage index obtained by obtained by substituting (20) into (19). The preceding results in (20) and (21) allows me to express the total wage bill of each firm as a product of the aggregate wage index and the respective firm's total employment

$$\int_0^1 W_t(l) N_t(i,l) = W_t^{\epsilon_w} N_t(i) \int_0^1 W_t(l)^{1-\epsilon_w} dl \tag{22}$$

$$= W_t N_t(i) \tag{23}$$

Capital Firms accumulate capital in the presence of investment adjustment costs. Each firm's capital $K_t(i)$ depreciates at rate δ and investments $I_t(i)$ made at time t become productive at $t+1$. The law of motion of capital follows

$$K_{t+1}(i) = (1-\delta) K_t(i) + I_t(i) - \zeta[I_t(i); \gamma_i], \tag{24}$$

where $\zeta[I_t(i);\gamma_i]$ is a convex adjustment costs

$$\zeta[I_t(i);\gamma_i] \equiv \frac{\gamma_i}{2}\left(\frac{I_t(i)}{K_t(i)} - \delta\right)^2 K_t(i) \geq 0 \tag{25}$$

where γ_i is a parameter. With convex adjustment costs, firms gradually integrate new capital into their capital structure as large investments are costly. For instance, a manufacturing firm installing a new large machine in a factory would need to temporarily halt production to do so as factory space is being used up in the installation process. However, production could still continue if a small machine is being installed using the same logic.

The aggregate supply of new capital is exogenous and inelastic, and the real price of purchasing a unit of investment $\frac{P_t^k}{P_t}$ is set to 1.

Price Setting Firms can choose their own prices $P_t(i)$ in the presence of nominal rigidities à la Rotemberg (1982). Under Rotemberg (1982) style pricing dynamics, firms face a convex cost when adjusting their prices because resources need to be allocated to actually change prices. A simple case of this type of adjustment cost is menu cost, for example, restaurants are required to allocate resources to pay for the printing of new menus if they change their prices. Conditional on the nominal price $P_{t-1}(i)$ firm i sets in the previous period, it faces the following adjustment cost when setting prices in the current period t

$$\frac{\gamma_p}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 Y_t \geq 0 \tag{26}$$

where γ_p is a parameter. In modelling nominal price rigidities, a common alternative to Rotemberg (1982) is Calvo (1983) staggered pricing where firms can reset prices in every period with a probability $1-\vartheta$. However, I chose Rotemberg (1982) instead of Calvo (1983) because with the former, pricing heterogeneity does not generate heterogeneity in the financial position of firms when markets are incomplete, i.e. the market for Arrow-Debreu type securities to insure against various states of the economy does not exist (Jermann and Quadrini, 2012). This suits the rest of the model setup. However, although Calvo (1983) and Rotemberg (1982) are based on different economic assumptions about price setting, Lombardo and Vestin (2008) found them to produce equivalent results to a first order of approximation. Furthermore, Keen and Wang (2007) show that the New Keynesian Philips curve produced under both pricing assumptions are identical at first order of approximation and by assuming a pricing duration through the Calvo-parameter ϑ, γ_p can be recovered, and vice versa. This will be important for the calibration of γ_p.

Credit Firms borrow by issuing one period secured-corporate bonds to households with interest rate $\lambda_t r_t$. Borrowing is only allowed against collataral and firms are required to pledge an exogenously determined fraction $0 < \nu(i) \leq 1$ of the liquidation value of their current capital as collateral:

$$B_t(i) \leq \nu(i) Q_t K_t(i) \tag{27}$$

where $B_t(i)$ is nominal debt and Q_t is the market value of one unit of installed capital – Tobins q. The proceeds from the bond issue finances the firm's current period investments

$$I_t(i) = B_t(i) \tag{28}$$

The combination of (27) and (28) gives the firms collateral constraint

$$I_t(i) \leq \nu(i) Q_t K_t(i) \tag{29}$$

The share of collatarizable capital $\nu(i)$ vary across firm types, with $0 < \nu^{\mathcal{L}} < \nu^{\mathcal{H}}$, where $\nu^{\mathcal{H}}$ and $\nu^{\mathcal{L}}$ are share of collaterizable capital for firms $i \epsilon \mathcal{H}$ and $i \epsilon \mathcal{L}$ respectively.

Dynamic Problem At each period t, each firm i takes its current capital $K_t(i)$, the aggregate price level P_t, aggregate wage level W_t, aggregate demand Y_t and unit price of capital P_t^k as given and chooses $\{Y_t(i)$,$K_{t+1}(i)$, $N_t(i)$, $I_t(i)$, $P_t(i)\}_{t \geq 0}$ to maximize the present value of expected real profits

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left(\frac{P_t(i)}{P_t} Y_t(i) - \frac{W_t}{P_t} N_t(i) - (1+\lambda_{t-1} r_{t-1}) \Pi_t^{-1} \frac{I_{t-1}(i) P_{t-1}^k}{P_{t-1}} - \frac{\gamma_p}{2} \left(\frac{P_t(i)}{P_{t-1}(i)} - 1 \right)^2 Y_t \right) \tag{30}$$

subject to a sequence production (18), capital accumulation (24), demand (17) and collateral (29) constraints. Furthermore, firms discount profits with the stochastic discount factor as they are owned by households who receive these profits as dividends.

The problem for each firm i is solved by using the Lagrangian method. First, I set the Lagrangian multiplier for the production constraint (18) as marginal cost $MC_t(i)$ since this is the shadow price for one additional unit of output $Y_t(i)$. The Lagranging multiplier for the capital accumulation process (24) is set to Q_t - Tobins q. Tobins q is the shadow lifetime value for one unit of installed capital. The Lagrangian multiplier for the collateral constraint (29) is $\mu_t(i)$ which is a measure of credit frictions resulting from the collateral constraint. In the model, I calibrate the value of $\nu^{\mathcal{H}}$ so that firms with high collateral have a non-binding collateral constraint ($\mu_t^{\mathcal{H}} = 0$) in steady state. On the contrary, I choose $\nu^{\mathcal{L}}$ to ensure that firms with low collateral have a binding collateral constraint ($\mu_t^{\mathcal{L}} > 0$) in steady state. I do this because in the absence of macroeconomic shocks in steady state, firms with high collateral should not be credit constrained as they have sufficient collateral to borrow. The opposite should hold for firms with low collateral. The expressions ($\mu_t^{\mathcal{H}} = 0$) and ($\mu_t^{\mathcal{L}} > 0$) for the non-binding and binding collateral constraints respectively are a result of the Karush-Kuhn-Tucker complementary slackness condition.

The equations (31) - (36) describe the optimality conditions of each firm i. The price setting condition is given by

$$\begin{aligned} \gamma_p \Pi_t(i)(\Pi_t((i) - 1) = \gamma_p E_t \left\{ \Lambda_{t+1} \Pi_{t+1}(i) \left(\Pi_{t+1}(i) - 1 \right) \frac{Y_{t+1}}{Y_t} \right\} \\ + \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_p - 1} \epsilon_p MC_t(i) \\ + \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_p} (1 - \epsilon_p) \end{aligned} \tag{31}$$

where $\Pi_t(i) = \frac{P_t(i)}{P_{t-1}(i)}$. When the economy is entirely populated by one set of firms that all behave identically in equilibrium, i.e. $\tau = 0$ or $\tau = 1$, (31) simplifies to

$$\gamma_p \Pi_t(i)(\Pi_t((i) - 1) = \gamma_p E_t \left\{ \Lambda_{t+1} \Pi_{t+1}(i) \left(\Pi_{t+1}(i) - 1 \right) \frac{Y_{t+1}}{Y_t} \right\} + \epsilon_p MC_t(i) + (1 - \epsilon_p) \tag{32}$$

The New Keynesian Philips curve is the first order linear approximation of (32) around steady state. The first order condition with regards to investments $I_t(i)$ gives

$$E_t \left\{ \Lambda_{t+1} \Pi_{t+1}^{-1} (1 + \lambda_t r_t) \frac{P_t^k}{P_t} \right\} + \mu(i) = Q_t \left(1 - \gamma_i \left(\frac{I_t(i)}{K_t(i)} - \delta \right) \right) \tag{33}$$

and given the fact that real price of purchasing one unit of investment $\frac{P_t^k}{P_t} = 1$ and the goods market clears $Y_t = C_t$, I use the Euler equation (11) to simplify (33) to

$$\frac{I_t(i)}{K_t(i)} = \delta + \frac{1}{\gamma_i} \frac{Q_t - [1 + \mu_t(i)]}{Q_t} \tag{34}$$

Interestingly, equation (34) shows that in steady state when the investment rate is given by $\frac{I_t(i)}{K_t(i)} = \delta$ from (24), then $Q_t = 1 + \mu_t(i)$. This shows that in steady state, Tobins q is equal to 1 for firms with high collaterizable capital ($\mu_t(i) = 0$ for $\forall i \; \epsilon \; \mathcal{H}$) and greater than 1 for firms with low collateralizable capital ($\mu_t(i) > 0 \; \forall i \; \epsilon \; \mathcal{L}$). This implies that in steady state – firms with low collateral value capital more than those with high collateral, which is intuitive as the former are borrowing constrained in steady state.

The optimality conditions with regards to capital $K_{t+1}(i)$ gives the expected marginal product of capital

$$\begin{aligned} \alpha E_t \left\{ \Lambda_{t+1} \frac{Y_{t+1}(i)}{K_{t+1}(i)} MC_{t+1}(i) \right\} &= Q_t - (1 - \delta) E_t \{ \Lambda_{t+1,t} Q_{t+1} \} \\ &- E_t \Bigg\{ \Lambda_{t+1} Q_{t+1} \Bigg[\gamma_i \frac{I_{t+1}(i)}{K_{t+1}(i)} \left(\frac{I_{t+1}(i)}{K_{t+1}(i)} - \delta \right) \\ &- \frac{\gamma_i}{2} \left(\frac{I_{t+1}(i)}{K_{t+1}(i)} - \delta \right)^2 \Bigg] + \nu(i) \mu_{t+1}(i) \Bigg\} \end{aligned} \tag{35}$$

where

$$MC_t(i) \equiv \frac{1}{1-\alpha} \frac{W_t}{P_t} \frac{N_t(i)}{Y_t(i)} \tag{36}$$

is the marginal cost. Equation (35) shows that the credit friction $\mu_t(i)$ created by the collateral constraint distorts the marginal product of capital across firm types, which is a source of misallocation (see Hsieh and Klenow, 2009). On the other hand, the credit friction $\mu_t(i)$ does not feed into the marginal cost $MC_t(i)$ of firms, which is reasonable as firms are only constrained with respect to capital investment and not working-capital (cash flows). Therefore, I expect the model to generate similar results to Khan and Thomas (2013) in the sense that the credit friction resulting from the collateral constraint does not generate heterogeneity in the employment decisions of each respective firm type.

4.3 Central Bank

The central bank is responsible for monetary policy and its monetary policy instrument is the nominal interest rate r_t. The central bank *strictly* targets inflation and adjusts the nominal rate according to the Taylor rule

$$\frac{1+r_t}{1+r_t^\star} = \left(\frac{1+r_{t-1}}{1+r^\star}\right)^{\rho_r} \left(\frac{\Pi_t}{\Pi^\star}\right)^{\phi(1-\rho_r)} e^{\varepsilon_t^m} \tag{37}$$

which is subject to a zero lower bound on nominal interest rates

$$r_t = \max\{0, r_t\} \tag{38}$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is gross inflation rate at time t, $r^\star$ and $\Pi^\star$ are steady state nominal interest rate and gross inflation rate respectively, $\phi > 1$ is the Taylor coefficient determining the responsiveness of the central bank's policy rate to inflation deviations from steady state target, ρ_r is the central bank's taste for interest rate smoothing, and the exogenous component of monetary policy follows a stochastic Markovian process

$$\varepsilon_t^m = \rho_m \varepsilon_{t-1}^m + u_t^m, \quad u_t^m \sim \mathcal{N}(0, \sigma_m) \tag{39}$$

where u_t^m is a monetary policy shock. The decision to restrict the central bank to *strictly* target inflation stems from the fact that I am calibrating the model to Sweden and unlike dual mandated monetary authorities such as the Fed, the Riksbanks mandate is only on price stability.

The zero lower bound restriction in (38) is necessary for both practical and numerical reasons. In practice, when interest rates are at the zero lower bound, the central bank looses its ability to sufficiently stimulate the economy through conventional monetary policy ("liquidity trap") (Svensson, 2001). In Section 3, I empirically show that at the zero lower bound, conventional monetary policy through policy rates fails to stimulate firms' investments. This finding additionally supports the implementation of a ZLB on policy rates in the model. From a numerically perspective, the monetary policy rule in (37) models the central bank's choice of nominal interest rates $\{r\}_{t=0}^{\infty}$ to be a continuous and increasing function of inflation. In such rules, the absence of a zero lower bound on nominal interest rates can generate multiple equilibria (see Benhabib, Schmitt-Grohé, and Uribe, 2001, and Gali, 2015).

4.4 Equilibrium and Market Clearing

A competitive equilibrium is defined as paths of aggregate allocations $\{C_t, N_t, Y_t, K_t, I_t\}_{t=0}^{\infty}$, *prices* $\{r_t, \Pi_t, w_t, w_t^{\star}, MC_t, Q_t\}_{t=0}^{\infty}$, *exogenous state processes* $\{A_t, \lambda_t, \varepsilon_t^m\}_{t=0}^{\infty}$ *and auxiliary variables* $\{\Lambda_{t+1}, S_{1,t}, S_{2,t}, \mu_t\}_{t=0}^{\infty}$ *such that*

1. The goods market clears $\int_0^1 C_t(i)di = \int_0^1 [Y_t(i) - \xi_t(i)]di$, where $\xi_t(i)$ is the output efficiency loss for good i due to the price adjustment cost (26),
2. the labor market clears $\int_0^1 N_t(l)dl = \int_0^1 N_t(i)di = N_t$,
3. the bond market clears $B_t = \int_0^1 B_t(i)$,

and

1. the households maximize utility (5) given budget (6) and labor demand constraints (7),
2. the firms maximize real discounted profits (30) give production (18), capital accumulation (24), goods demand (17) and collateral constraints (29)

3. the central bank follows monetary policy (37).

The model is linearized and solved using first-order approximation around a non-stochastic zero inflation rate steady state ($\Pi^\star = 1$) in Dynare. I solve the model under two regimes: one where the economy is entirely populated by high collateral $\mathcal{H}$ firms and $\tau = 1$, and another regime with only low collateral $\mathcal{L}$ firms and $\tau = 0$. This method is analytically convenient in that it allows me to perform comparative dynamics of the economy as a result of exogenous variations in firms' collateral. The model equilibrium under each regime is characterized by a dynamic system of 18 equations presented in Section B.1. These 18 equations are used to solve for the 18 variables $\{C_t, N_t, Y_t, K_{t+1}, I_t, r_t, \Pi_t, w_t, w_t^\star, MC_t, Q_t, A_t, \lambda_t, \varepsilon_t^m, \Lambda_{t+1}, S_{1,t}, S_{2,t}, \mu_t\}$.

4.5 Parametization

The unit of time in the model is a quarter and the parameters are calibrated to match moments in Swedish macroeconomic data. I set the discount factor $\beta = 0.98$ to match the average quarterly Riksbank policy rate of 2% in steady state. I set $\eta = 1.33$ which implies a Frisch elasticity of labor supply of 0.75. This is consistent with the extensive and intensive margin point estimates of labor elasticities in the micro data found in a meta study by Chetty et al. (2011). I set the weight on disutility of labor $\zeta = 0.45$. The relative risk aversion parameter $\sigma = 1$, giving a log utility in consumption. A log utility in consumption allows long-run employment to be unaltered by fluctuations in technology A_t as the income and substitution effects created by shocks in A_t offset each other (see Gali, 2015). I choose an elasticity of substitution between labor varieties $\epsilon_w = 12.14$ to target the 6.4% natural unemployment rate in the Swedish economy. Gali (2015) shows that wage markup $\frac{\epsilon_w}{\epsilon_w - 1} = \exp\{\bar{u}\eta\}$ under the assumption that the natural unemployment rate $\bar{u}$ is small and the wage markup $\frac{\epsilon_w}{\epsilon_w - 1}$ is constant over time. With these assumptions and the already selected value of η, I set $\epsilon_w = 12.14$ which gives wage markup of around 1.09. I set the wage stickiness parameter $\omega = 0.75$. The value for ω implicitly implies a wage adjustment duration of four quarters (1-year) which is in line with the institutional setting of the Swedish labor market as a high proportion of wages are negotiated through collective bargaining agreements between unions and employers through annual negotiation rounds.[10] The depreciation rate $\delta = 0.03$ is chosen to match the average investment rate $\frac{I_t}{K_t}$ of the Swedish business sector. This is because in steady

Table 6: Parametization

Notation	Description	Value
β	Discount factor	0.98
σ	Risk aversion	1
η	Inverse Frisch elasticity	1.33
ζ	Weight on disutility of labor	0.45
α	Capital share	0.32
δ	Depreciation rate	0.03
ω	Wage stickiness	0.75
ϵ_p	Goods elasticity of substitution	2.59
ϵ_w	Labor elasticity of substitution	12.14
γ_p	Price adjustment	17
γ_i	Investment adjustment	5.95
ρ_a	Technology shock persistence	0.96
ρ_λ	Risk premium shock persistence	0.22
ρ_m	Monetary policy shock persistence	0.12
ρ_r	Interest rate smoothing	0.97
ϕ	Taylor coefficient on inflation	1.5
High Collateral		
τ	Share of high collateral firms	1
$\nu^{\mathcal{H}}$	Capital pledge ratio as collateral	0.03
Low Collateral		
τ	Share of high collateral firms	0
$\nu^{\mathcal{L}}$	Capital pledge ratio as collateral	0.02

Notes: The table presents parameter values under the baseline calibration of the model.

state, $\delta = \frac{I^\star}{K^\star}$ where the $\star$ denote steady state values. I choose the capital share $\alpha = 0.32$ by subtracting the average labor share, i.e. labor cost as a share of total production in the Swedish business sector, from 1. I follow the method by Gollin (2002) and adjust the labor share by the proportion of the labor force that are self-employed. I set $\epsilon_p = 2.59$ to target price markup of 1.63. This is the average price markup of firms in the Swedish data (Serrano) empirically estimated by Agrawal, Gaurav, and Suveg (2021) following the method by De Loecker and Warzynski (2012). I set $\gamma_p = 17$

[10] The labor union density in Sweden has average at about 71% over the last two decades – second highest among OECD countries (OECD).

to target a price duration of four quarters, i.e. that firms change their prices every four quarters. Keen and Wang (2007) show that the identical New Keynesian Philipps curves produced under Rotemberg (1982) and Calvo (1983) allows γ_p and the Calvo parameter ϑ to be linked through $\gamma_p = \frac{(\epsilon_p-1)\vartheta}{(1-\vartheta)(1-\beta\vartheta)}$. So by assuming a four quarter pricing duration through the Calvo parameter $\vartheta = 0.75$, I can recover $\gamma_p = 17$. I assume a four-quarter price duration based on the findings of Apel, Friberg, and Kerstin (2005) that the median Swedish firm adjust the price of their main product once per year. The investment adjustment cost parameter $\gamma_i = 5.95$ is estimated from the model using the Generalized Method of Moments Toolbox in Dynare to match the standard deviation of the aggregate investment rate in the Swedish business sector. I set the interest rate smoothing parameter $\rho_r = 0.97$ which I estimate from an AR(1) of the demeaned Riksbank policy rate. I set the Taylor coefficient on inflation $\phi = 1.5$ which is about the

Table 7: Matched Moment in Estimation of γ_i

Moment	Description	Data	Model
$\sigma\left(\frac{I_t}{K_t}\right)$	Standard dev. Investment rate	0.033	0.033

Notes: The table presents moments from the model and data resulting from the estimation of γ_i using Generalized Method of Moments (GMM) in Dynare. The GMM toolbox in Dynare estimates a value γ_i that minimizes the distance between the theoritical moment and data given other parameter values. The data moments are computed from a seasonally adjusted and HP-filtered time series of the investment rate in the Swedish business sector between 1980:Q1 – 2022:Q4. The data is seasonally adjusted using X12-ARIMA SEATS and detrended using the HP-filter with smoothing parameter $\lambda^{HP} = 1600$. The model moments are theoretical moments from the model calibrated under the regime when $\tau = 1$.

medium range in the literature. I set the monetary policy shock persistence $\rho_m = 0.12$ and risk premium shock persistence $\rho_\lambda = 0.22$. These are means of the posterior distributions of each respective shock found in Smets and Wouters (2007). The persistence in productivity shocks $\rho_a = 0.96$ is estimated from an AR(1) process of detrended aggregate total factor productivity (TFP) $\hat{a}_t$ in the Swedish business sector. I follow Jermann and Quadrini (2012) and estimate TFP as a Solow-residual from a linearized version of the production function (18) using empirically observed output, capital and employment in the business sector. In specific, detrended TFP $\hat{a}_t = \hat{y}_t - \alpha\hat{k}_t - (1-\alpha)\hat{n}_t$, where $\hat{y}_t$, $\hat{k}_t$, $\hat{n}_t$ are log-deviations of output, capital and employment from their deterministic trend respectively. The standard deviations of the monetary policy shock u^m, technology shock u^a and risk premium shock u^λ are set to 0.0025, 0.01 and 0.0020 respectively.

The shocks are all uncorrelated.

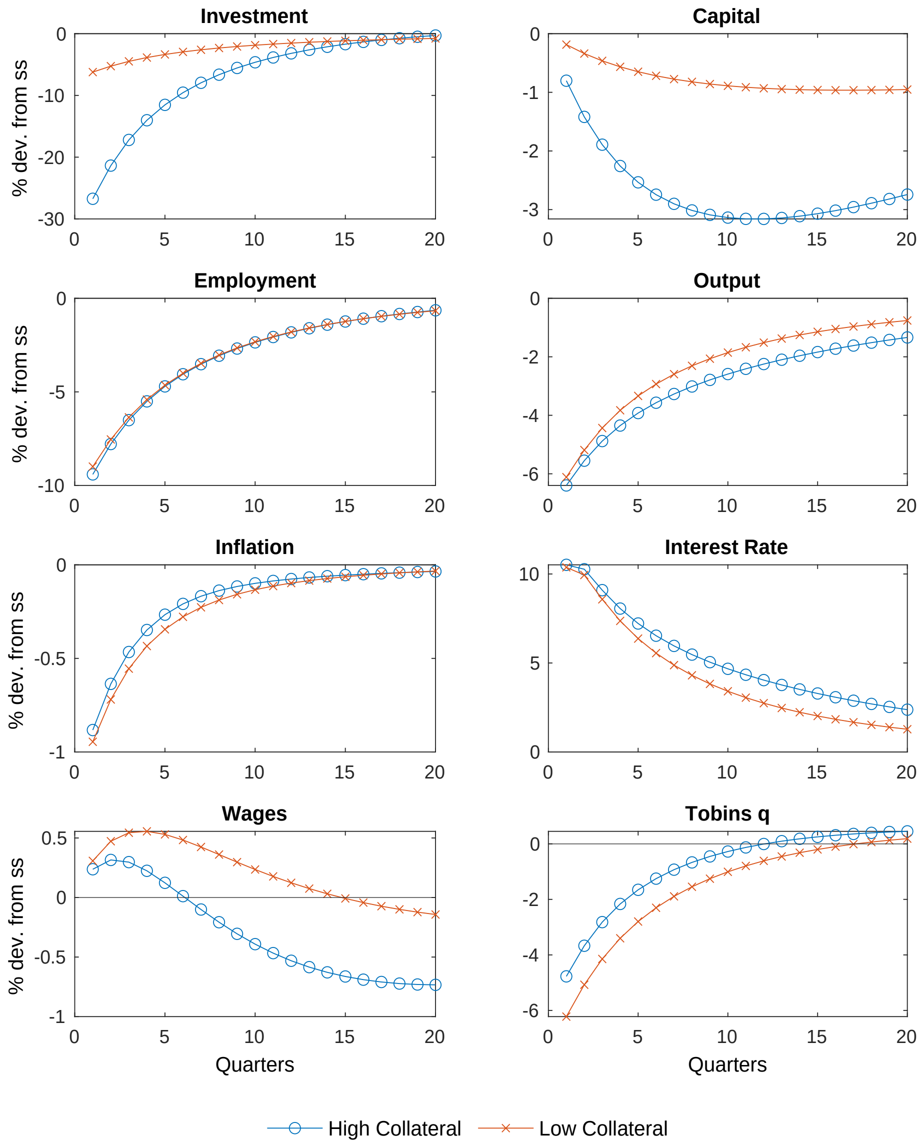
The collateral pledge ν is firm-type and regime specific. In the regime where the economy is entirely populated by high collateral $\mathcal{H}$ firms and $\tau = 1$, I set $\nu^{\mathcal{H}} = 0.03$ to ensure firms are not credit constrained by collateral ($\mu^{\star} = 0$) and Tobins q is 1 in steady state. In the alternative regime where the economy is entirely populated by low collateral $\mathcal{L}$ firms and $\tau = 0$, I arbitrarily set $\nu^{\mathcal{L}} = 0.02$ to ensure firms are constrained by collateral ($\mu^{\star} = 0.5 > 0$) and Tobins $q = 1.5 > 1$ in steady state.

4.6 Economic Dynamics

Baseline Calibration Figure 4 presents impulse responses of a set of endogenous variables to a 25 basis point monetary policy contractionary shock. The monetary policy shock reduces investments in both collateral regimes, but the investment responses display a stark heterogeneity across regimes. The decline in investments from its steady state level is around 11.2 percentage points more in the high- compared to the low- collateral regime four-quarters after the shock. These results are qualitatively consistent with the empirical evidence in Section 3.

A possible explanation for the heterogeneous investment responses is the reaction of Tobins q (value of capital) after the monetary policy shock. Since firm borrowings and investments are constrained by the value of capital from equations (27) and (28), its reduction due to monetary policy shocks should have an impact on investments. Following the monetary policy shock, Tobins q declines from its steady state level and capital becomes less valuable under both regimes. Although the decline in Tobins q from steady state is 2.56 percentage points more in the low collateral regime, capital is still more valuable in the aforementioned regime compared to the high collateral regime. This is because in steady state, Tobins q is relatively higher when collateral is low as firms are constrained. With capital even being less valuable after the monetary policy shock when collateral is high, investments decline by more as it is constrained by the value of capital in equations (27) and (28). In short, a contractionary monetary policy reduces the value of capital that firms borrow against. This has a stronger impact on firms that are more reliant on collateral ($\mathcal{H}$ firms) for borrowing and investments. Moreover, it can be seen that collateral operates as an economic multiplier that propagates the transmission of monetary policy to real economic variables such as investments.

Figure 4: Impulse Responses to a Monetary Policy Shock



Notes: The figure plots impulse responses of some endogenous variables to a 25 basis points monetary policy shock. The response units are expressed as % deviations from steady state and the time period is a quarter.

As a result of declining investments and capital following the monetary policy shock, aggregate output is also negatively impacted. Similarly, the percentage decline in output from steady state is greater in the high- compared to the low- collateral regime. The relatively higher decline in output in the high collateral regime is reflected in the relatively higher prices (inflation). This is because firms face a downward slopping demand curve (17). In terms of employment dynamics, there is almost no heterogeneity across collateral regimes. This is expected as the collateral constraint only applies to capital investments and not working capital. Khan and Thomas (2013) find a similar dynamic. For wages, they increase by 0.55 and 0.22 percent from steady state four-quarters after the shock when collateral is low and high respectively. The contractionary shock increases the nominal interest rate upon impact. This eventually declines and reverts back to steady state as the central bank responds to the deflationary pressures. However, the interest rate path is higher and reverts back to steady state at a slower pace in the high collateral regime.

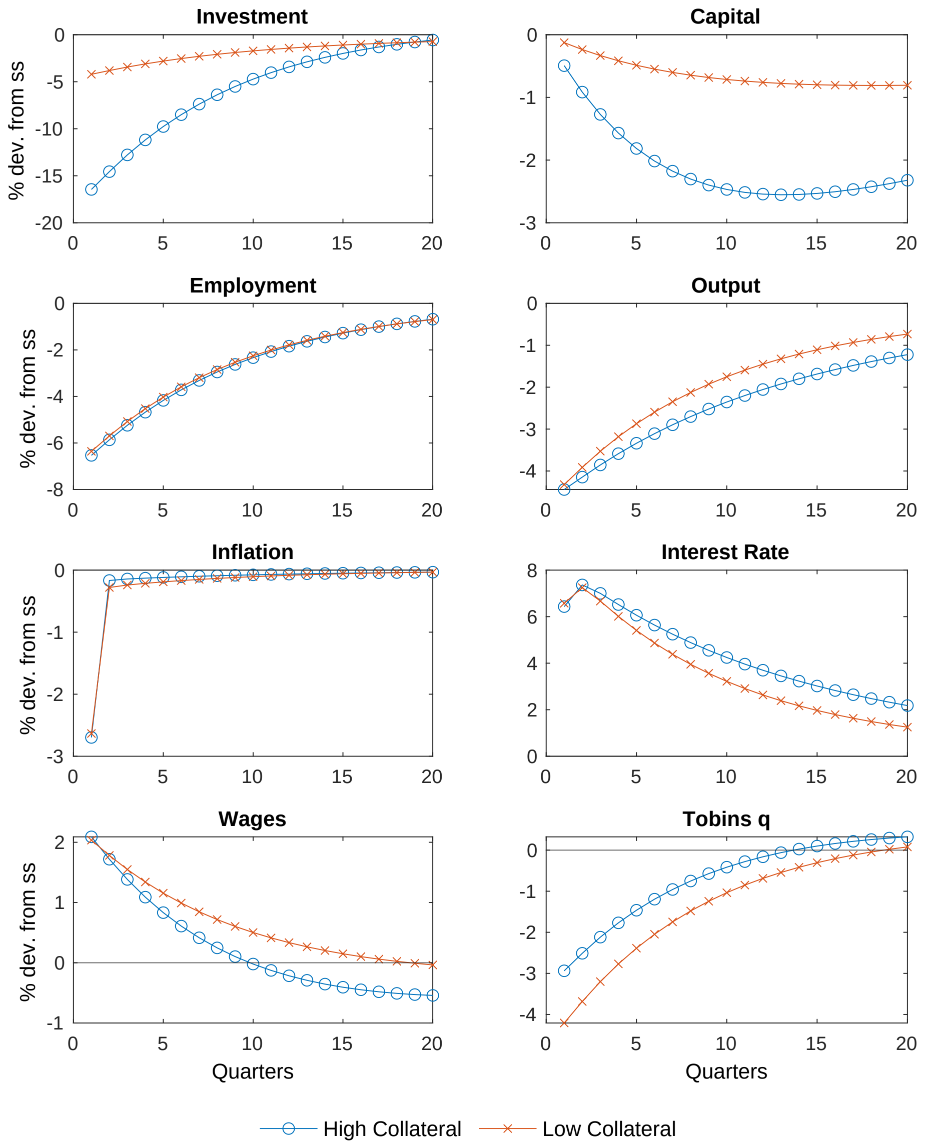
Alternative Specification The model is also calibrated under a specification where firms can freely adjust prices and the price adjustment parameter $\gamma_p = 0$. Figure 5 shows impulse responses from this specifications due to a monetary policy shock. The responses of the endogenous variables, except for inflation and wage dynamics, are qualitatively the same but quantitatively smaller compared to the baseline calibration. Compared to the baseline calibration, the differential in investment responses between the high- and low-collateral regime is 8.08 percentage points four-quarters after the monetary policy shock.

In addition, inflation shows a very different dynamic when prices are flexible. A contraction monetary policy shock puts a quicker and greater downward pressure on inflation when prices are flexible, which is intuitive as firms can costlessly reduce prices to respond to tighter economic conditions. The responses to prices changes are also much more identical in the high and low- collateral regimes when prices are flexible. This indicates that in the absence of price adjustment costs, the pricing decisions of firms are more independent from external finance constraints.

The conclusion I derive from the model is that the degree to which assets (capital) are collaterized in the economy impacts the transmission of monetary policy to investments.

Complementary to the evidence in Section 3, it can be seen that investment responses to monetary policy are stronger when firms have pledge a higher fraction of assets (capital) as collateral. This is because monetary policy creates readjustments in asset prices (Tobin q) that firms borrow against to make investments. These readjustments

Figure 5: Impulse Responses to a Monetary Policy Shock under Flexible Prices



Notes: The figure plots impulse responses of some endogenous variables to a 25 basis points monetary policy shock. The plot is based on a model calibration with flexible prices and $\gamma_p = 0$. The response units are expressed as % deviations from steady state and the time period is a quarter.

has a much stronger impact when firms are more dependent on collateral for borrowing.

Policy Evaluation The central bank's primary policy objective is to minimize inflation rate deviations from its steady state target: $\log(\Pi_t) - \log(\Pi^\star)$. It does this by choosing a nominal interest rate r_t according to the Taylor rule (37). Let's assume the central bank faces a loss at each period t inflation deviates from its steady state target

$$\mathfrak{L}_t = (\pi_t - \pi^\star)^2 \tag{40}$$

where $\pi_t = \log(\Pi_t)$ is the inflation rate. The aggregate loses over T periods is quantified as

$$\mathfrak{L} = \sum_{t=0}^{T}(\pi_t - \pi^\star)^2 \tag{41}$$

and the average loss during the T periods is

$$\begin{aligned}\overline{\mathfrak{L}} &= \frac{1}{T}\sum_{t=0}^{T}(\pi_t - \pi^\star)^2 \\ &= \mathrm{var}(\pi_t)\end{aligned} \tag{42}$$

where the second equality in (42) is based on the fact that steady state inflation rate $\pi^\star = E\{\pi_t\}$ is the unconditional mean of the inflation rate when T is large. Equation (42) shows that the central bank's average loss is equivalent to the variance of inflation which is intuitive as the central bank's core policy objective is to minimize inflation deviations from its state state. The loss function in (40) is quadratic to ensure that loses are incurred both when inflation is above or below target.

Table 8: Central Bank's Average Loss $\overline{\mathfrak{L}}$

Regime		Baseline	Flexible Prices
High Collateral	$\{\tau = 1, \nu = 0.03\}$	1.1834	7.4569
Low Collateral	$\{\tau = 0, \nu = 0.02\}$	1.4273	7.0989

Notes: The table presents the average central bank loss $\overline{\mathfrak{L}}$ under the different collateral regimes. The losses are based on model simulated data for $T = 1000$ periods. The baseline calibration are based on parameter values in Table 6. The flexible price calibration sets $\gamma_p = 0$.

Table 8 evaluates the central bank's average loss conditional on the share of firms with high collateral τ. These are based on model simulations for $T = 1000$ periods. The central bank faces a higher loss when firms have low- compared to high collateral under the baseline calibration. This indicates that credit friction, particularly collateral, serve as an important channel to which monetary policy can stabilize inflation in the economy.

In the case where prices are flexible, the central bank's loses are in general higher as inflation is more volatile. This is intuitive as firms can costlessly change prices to adapt to economic conditions. However, in contrast to the baseline specification, the central bank's loses are greater in the high- compared to low collateral regime when prices are flexible. The interaction of nominal price rigidities and collateral constraints is beyond the scope of this paper, so I will not dive deeper into the mechanisms. Nevertheless, it could be interesting for further research.

5 Discussion

In the previous sections, I use Swedish data and a general equilibrium model to show the role of collateral in altering the transmission of monetary policy to firms' investments. Both the model and the empirical exercises show that the investment responses to monetary policy are stronger when firms are highly collateralized. Moreover, I show that the degree to which assets are collateralized in the economy have implications to the effectiveness of monetary policy in achieving price stability. In this section, I discuss the internal and external validity of the results and relate it to previous findings.

The main threat to the internal validity of an empirical and numerical study is the strength of identification. In the empirical case, this is the identification of the exogenous variable – the monetary policy shock. With regards to the model identification, this means satisfying the Blanchard and Kahn (1980) conditions for a unique and stable equilibrium. I identified monetary policy shocks using the high frequency approach in Krueger and Kuttner (1996) which is a standard for identification in the literature. Moreover, I went further to ensure exogeniety of the shocks with regards supplementary economic information released during monetary policy announcements by using the normative approach in Miranda-Agrippino and Giovanni (2021). Preferably, I would have liked to construct monetary policy shocks for even longer periods, for instance from 1997 which is the initial panel year in Serrano. However, due to institutional limitations in that interest rate derivatives such as the 30-day Stina were introduced in 2007, doing this was impossible. Under both sets of identifying assumptions nevertheless, the empirical results show a unified message in that firms that are highly collaterized are more responsive to monetary policy shocks. Putting these results in the context of past empirical finding in Jeenas (2019) and Otonello and Winberry (2020), I show that the collateral channel, not leverage or liquidity, is the most prevalent channel to which monetary policy transmits to firms' investments. This is a rather new empirical result in the literature and should have future implications in the modelling of credit frictions in DSGE models.

The model in the paper is identified in that the Blanchard and Kahn (1980) conditions are satisfied and I was able to find a unique and stable equilibrium. Moreover, the model dynamics corroborate findings in a catalogue of papers including Bernanke, Gertler, and Gilchrist (1999) and Iacoviello (2005) in that collateral constraints amplify the transmission of monetary policy to firms investments and macroeconomic aggregates. Though not directly quantitatively comparable due to the different model assumptions and calibrations in this paper and the aforementioned, the dynamics generated by collateral constraints are consistent through and through. This gives my model results some external validity. However, one possible addition to the model could have been an export sector of the economy. With this, I could perhaps capture developments in foreign markets, which are important for a small open economy such as Sweden. However, due to limitations in time and complexity, I leave this for future research.

6 Conclusion

In this paper, I have studied the role of collateral in the transmission to monetary policy to firms' investments. First, I use Swedish firm-level data to empirically show that highly collateralized firms, i.e. firms that pledge a relatively high share of assets as collateral, are more responsive to monetary policy. After a contractionary monetary policy shock, these firms significantly reduce investments more than firms with low collateral. This results was further supported by evidence of collateral based borrowing constraints that tighten in the presence of monetary policy shocks. Furthermore, I show collateral, not leverage or liquidity, to be the prevalent source of credit frictions that monetary policy transmits to firms' investments. This is a novel contribution in the empirical literature in credit frictions. Second, I build a New Keynesian model with heterogeneous credit constrained firms that I calibrate to Swedish data. Similar to the empirical results, I also find that investments of firms with high collateralizable capital are more responsive to monetary policy shocks. These results have policy implications as I also showed monetary policy to be more powerful in achieving price stability when firms in the economy are relatively highly collateralized.

This paper provides numerous avenues for further research. For instance, studying the interaction of monetary policy and collateral in the entry and exit decision of firms could be interesting. In addition, one can also perform employer-employee matching using the firm-level data in Serrano and household administrative data from Statistics Sweden to study the heterogeneous impact of monetary policy on employees of firms' with varying collateral. This impact of monetary policy on labor market and employment dynamics at the individual level could be studied using the methods and results from this paper as precedent.

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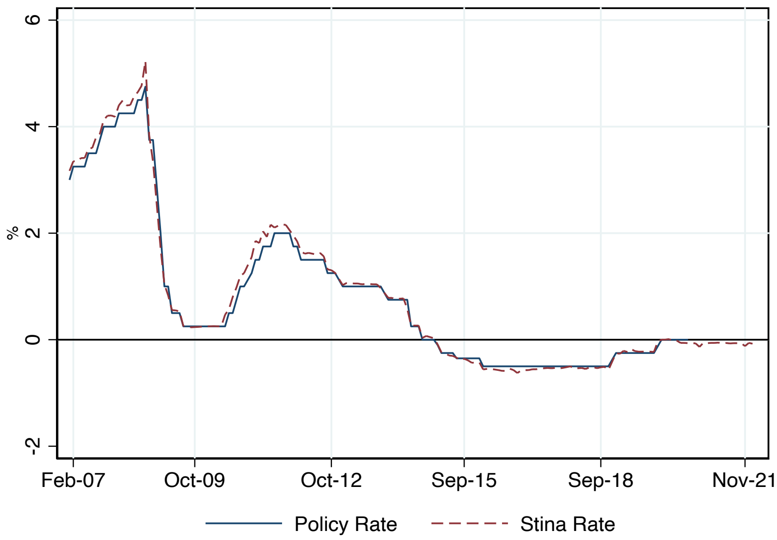
A Additional Empirical Results

Figure A.1: Policy and Swap Rate



Notes: The figure plots the Riksbank policy rate and the Stina swap rate from 2007 to 2021. The two time series have a correlation of 0.998. The units in the y-axis are in %. Source: Riksbank (2023) and Refinitiv (2023)

Table A.1: Sampling Restrictions

		Observations	Firms	Age	Size
0.	Full sample	97,265	19,481	14	44
1.	Excl. financial, real estate and utility firms	63,485	13,835	15	48
2.	Excl. firms that are less than two years old or missing age	61,649	13,342	15	48
3.	Excl. firms that have less than two employees or missing employee	58,548	12,590	15	51
4.	Excl. firms that are not limited liability companies	58,190	12,526	15	51
5.	Excl. firms that are state, county or municipal owned	57,380	12,422	15	51
6.	Excl. firms that are inactive	57,164	12,369	15	51
7.	Excl. firms undergoing restructuring, bankruptcy, liquidation or mergers	56,751	12,313	15	51
8.	Excl. firms with missing or negative sales, assets, equity, collateral, leverage, liquidity and sector codes	37,122	7,654	18	61

Notes: The table presents sampling restrictions applied to the firm-level data from Serrano. Age and Size refers to median age and number of employees of the sample respectively.

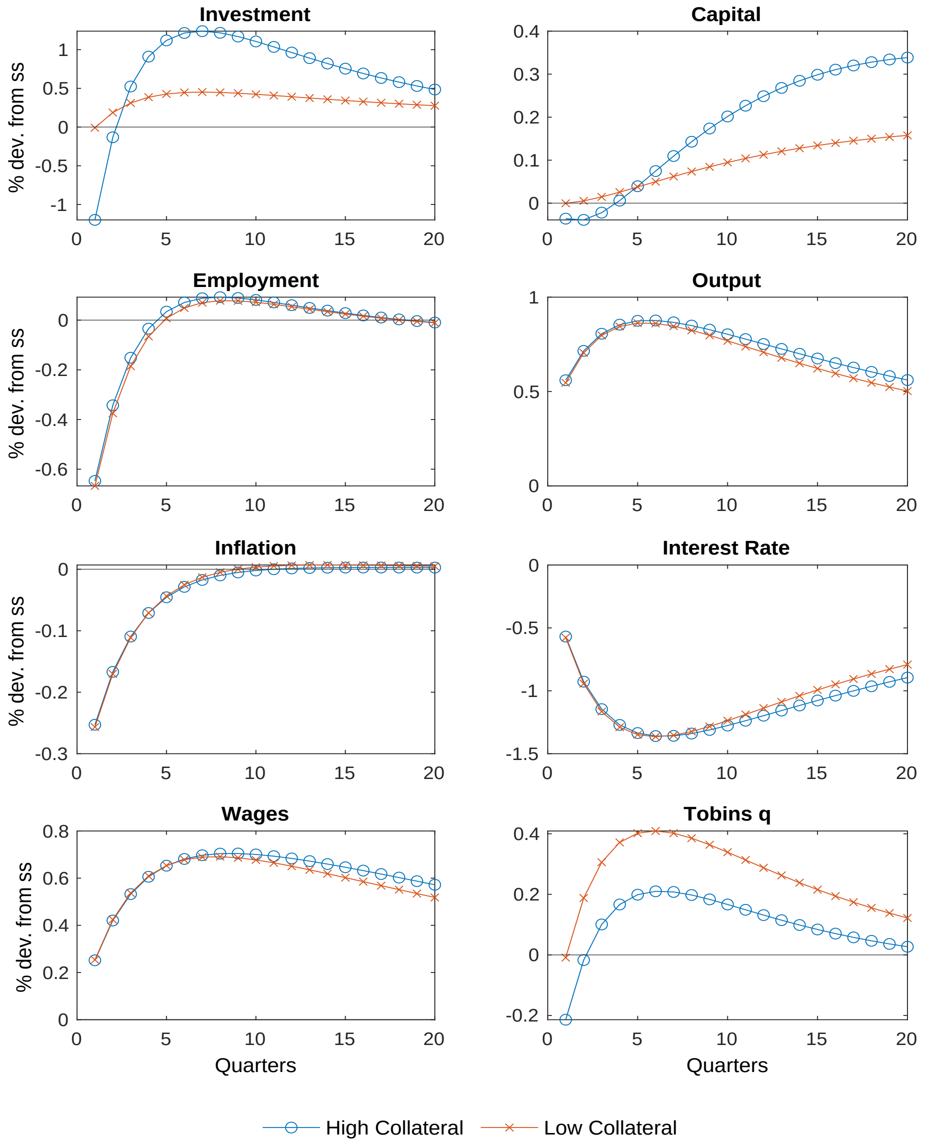
Table A.2: Estimates for Economic Forecasts on Monetary Policy Shocks

	(1)
y_0	-0.003
	(0.005)
y_1	-0.004
	(0.013)
y_2	0.005
	(0.018)
π_0	-0.014
	(0.014)
π_1	-0.010
	(0.021)
π_2	0.027
	(0.021)
r_0	-0.060**
	(0.026)
r_1	0.130***
	(0.044)
r_2	-0.068**
	(0.027)
Δy_0	-0.008
	(0.010)
Δy_1	-0.010
	(0.025)
Δy_2	-0.016
	(0.030)
$\Delta \pi_0$	-0.018
	(0.040)
$\Delta \pi_1$	0.024
	(0.038)
$\Delta \pi_2$	-0.018
	(0.041)
Δr_0	0.238**
	(0.094)
Δr_1	0.048
	(0.076)
Δr_2	-0.033
	(0.062)
R^2	0.513
Observations	83

Notes: The table reports estimates for specification 3 on the 85 monetary policy announcements between 2007 to 2021 that the Riksbank released economic forecasts. The coefficient estimates are in %. Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

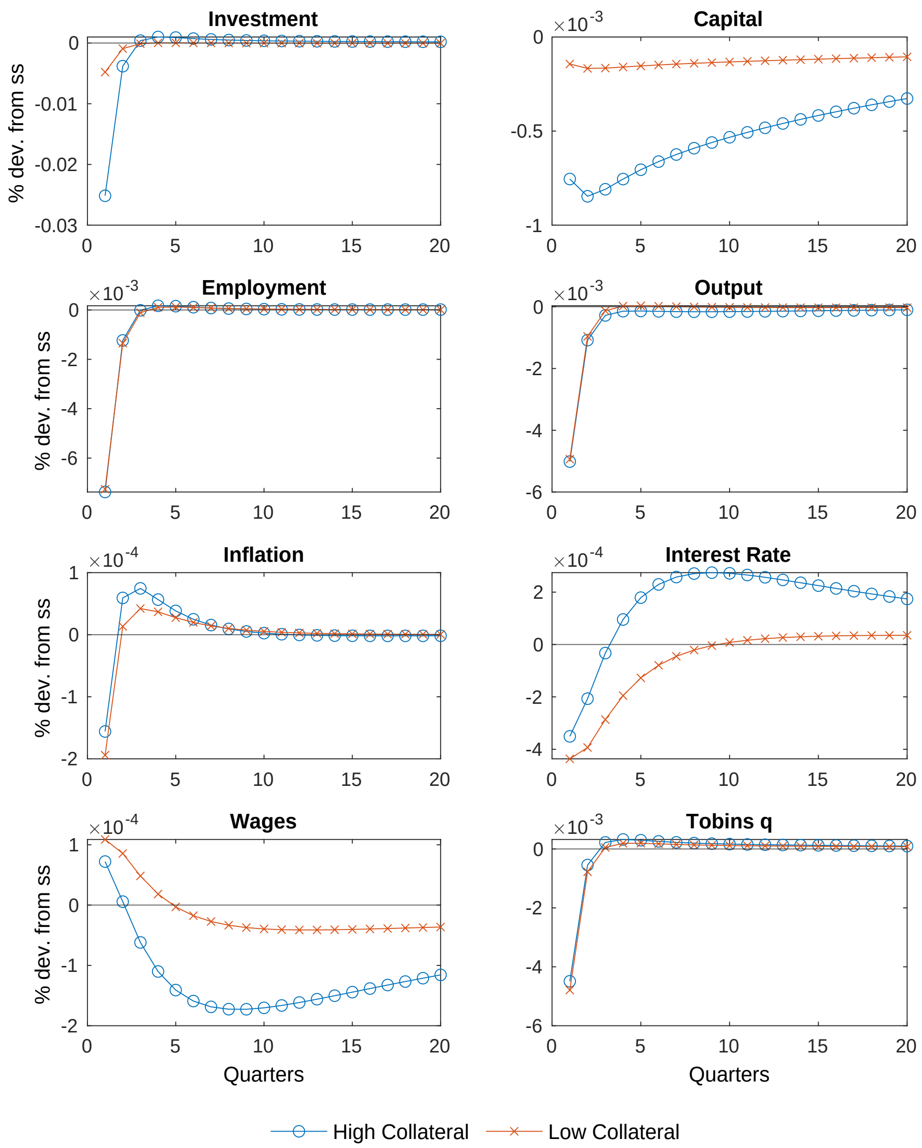
B Additional Model Results

Figure A.2: Impulse Responses to a Technology Shock



Notes: The figure plots impulse responses of some endogenous variables to a 1 percentage point technology shock. The response units are expressed as % deviations from steady state and the time period is a quarter.

Figure A.3: Impulse Responses to a Risk Premium Shock



Notes: The figure plots impulse responses of some endogenous variables to a 20 basis point risk premium shock. The response units are expressed as % deviations from steady state and the time period is a quarter.

B.1 Dynamic System

$$\Lambda_{t+1} = \beta E_t \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \tag{43}$$

$$C_t^{-\sigma} = \beta E_t \left\{ C_{t+1}^{-\sigma} \Pi_{t+1}^{-1} \right\} (1 + \lambda_t r_t) \tag{44}$$

$$w_t^{\star,1+\epsilon_w\eta} = \frac{\epsilon_w}{\epsilon_w - 1}\frac{S_{1,t}}{S_{2,t}} \tag{45}$$

$$S_{1,t} = \zeta w_t^{\epsilon_w(1+\eta)} N_t^{1+\eta} + \beta\omega E_t\{\Pi_{t+1}^{\epsilon_w(1+\eta)} S_{1,t+1}\} \tag{46}$$

$$S_{2,t} = C_t^{-\sigma} w_t^{\epsilon_w} N_t + \beta\omega E_t\{\Pi_{t+1}^{\epsilon_w - 1} S_{2,t+1}\} \tag{47}$$

$$\begin{aligned} \alpha E_t\left\{\Lambda_{t+1}\frac{Y_{t+1}}{K_{t+1}}MC_{t+1}\right\} = Q_t - (1-\delta)E_t\{\Lambda_{t+1}Q_{t+1}\} \\ - E_t\Bigg\{\Lambda_{t+1}Q_{t+1}\Bigg[\gamma_i\frac{I_{t+1}}{K_{t+1}}\left(\frac{I_{t+1}}{K_{t+1}} - \delta\right) \\ - \frac{\gamma_i}{2}\left(\frac{I_{t+1}}{K_{t+1}} - \delta\right)^2\Bigg] + \nu\mu_{t+1}\Bigg\} \end{aligned} \tag{48}$$

$$\frac{I_t}{K_t} = \delta + \frac{1}{\gamma_i}\frac{Q_t - [1+\mu_t]}{Q_t} \tag{49}$$

$$\begin{aligned} \gamma_p\Pi_t(\Pi_t - 1) = \gamma_p E_t\left\{\Lambda_{t+1}\Pi_{t+1}\left(\Pi_{t+1} - 1\right)\frac{Y_{t+1}}{Y_t}\right\} \\ + \epsilon_p MC_t + (1-\epsilon_p) \end{aligned} \tag{50}$$

$$MC_t = \frac{1}{1-\alpha}\frac{N_t}{Y_t}w_t \tag{51}$$

$$w_t = \left[(1-\omega)w_t^{\star 1-\epsilon_w} + \omega w_{t-1}^{1-\epsilon_w}\Pi_t^{\epsilon_w - 1}\right]^{\frac{1}{1-\epsilon_w}} \tag{52}$$

$$C_t = Y_t - \frac{\gamma_p}{2}(\Pi_t - 1)^2 Y_t \tag{53}$$

$$K_{t+1} = (1-\delta)K_t + I_t - \frac{\gamma_i}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t \tag{54}$$

$$Y_t = A_t K_t^{\alpha} N_t^{1-\alpha} \tag{55}$$

$$\frac{1+r_t}{1+r_t^{\star}} = \left(\frac{1+r_{t-1}}{1+r^{\star}}\right)^{\rho_r}\left(\frac{\Pi_t}{\Pi^{\star}}\right)^{\phi(1-\rho_r)} e^{\varepsilon_t^m} \tag{56}$$

$$\log(\lambda_t) = \rho_\lambda \log(\lambda_{t-1}) + u_t^{\lambda} \tag{57}$$

$$\log(A_t) = \rho_a \log(A_{t-1}) + u_t^{a} \tag{58}$$

$$\log(\varepsilon_t^m) = \rho_m \log(\varepsilon_{t-1}^m) + u_t^{m} \tag{59}$$

$$0 = \min\{Q_t\nu K_t - I_t, \mu_t\} \tag{60}$$

B.2 Data Sources for Calibration

1. Statistics Sweden. *National Accounts: Quarterly and Annual Estimates.*

    (a) GDP production approach (ESA2010) by observations, industrial classification NACE Rev. 2 and quarter

    (b) Labor costs (ESA2010), current prices, SEK million by observations, industrial classification NACE Rev. 2 and quarter

    (c) Gross fixed capital formation (ESA2010) by observations, industrial classification NACE Rev. 2 and quarter

    (d) Balance sheets (ESA2010), end of year, net, current prices in SEK million by sector, type of asset and year.[11]

    (e) Employed persons aged 15-74 (LFS) by degree of attachment to the labour market, sex and age, previous definitions. Quarter 1970K1 - 2020K4

2. Organization for Economic Co-operation and Development (OECD). *Main Economic Indicators*

    (a) GDP Implicit Price Deflator in Sweden, retrieved from FRED.

    (b) Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts (ICTWSS)

[11]The data is converted from annual to quarterly frequency using a cubic-spline interpolation.