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The Fed Information Effect and Firm-Level Investment: Evidence and Theory

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Abstract: We present evidence that the Fed's private information about economic conditions revealed through Federal Open Market Committee announcements affect firm investment. We use firm-level investment data and analyst forecasts of firm fundamentals to document three facts. First, the investment rate sensitivity to Fed information is greater for more cyclical firms. Second, revisions in analyst forecasts of firm fundamentals are greater for more cyclical firms. Third, the investment response is consistent with changes in firm profitability following Fed announcements. We propose a HANK model to explain these patterns. Our model rationalizes the slow decline in inflation in 2022–23 despite aggressive policy rate hikes.

JEL classification: E22, E52, G31

Key words: monetary policy, Fed information effect, heterogeneous investment response

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1 Introduction

The "Fed Information effect" posits that Fed announcements influence the public's forecast of future economic conditions because such announcements reveal the Fed's private information regarding economic fundamentals. Existing evidence for the Fed information effect is based on revisions in professional forecasts of key aggregate macroeconomic variables, such as inflation, following Fed announcements (see, e.g., Romer and Romer (2000) and the literature following it). Recently, however, existing evidence of the Fed information effect have been challenged by Bauer and Swanson (2022, 2023) who show that such aggregate level results are not robust to controlling for macroeconomic news released prior to Fed announcements.

In this paper, we employ firm-level investment data and analyst forecasts of firm fundamentals to provide evidence for the Fed information effect. Firm-level data offers at least two advantages compared to existing methods that use aggregate time-series variables in identifying Fed information effects. First, heterogeneity in firms' investment responses can be used to detect Fed information effects in a large cross-section which provides greater statistical power compared to a few time-series of aggregate variables. This approach relies on the logic that if Fed information affects aggregate economic conditions, we expect firm policies of more cyclical firms to have a greater sensitivity to such information. Second, analyzing the cross-section helps inform the channel through which Fed information might affect firm policies.

To identify a Fed information shock, we use an existing measure proposed by Jarociński and Karadi (2020) (henceforth "JK") that infers a Fed information shock from the comovement of the aggregate stock market and interest rates over a 30-minute window around FOMC announcements. To see how the stock market helps isolate the Fed's private information regarding future economic fundamentals, consider a larger than expected increase in the Fed funds rate. Absent any mention of a change in economic outlook in the accompanying FOMC announcement, the stock market is expected to decline. However, the stock market can increase if the FOMC announcement conveys an upward revision in the Fed's future economic outlook that is sufficiently large to offset the negative effect of the interest rate increase. JK use this logic to separate a monetary policy shock into two components: a Fed information component which they refer to as a Central Bank Information shock (henceforth "CBI shock") and a conventional monetary shock (henceforth "MP shock"). The CBI (MP) shocks are identified from positive (negative) comovements of interest rates and the aggregate stock market. JK provide evidence to show that realizations of the CBI shock does indeed align with the Fed's economic assessment as mentioned in the FOMC announcement. Additionally, in Appendix A, we show that the CBI shock is positively correlated with revisions in the Fed's internal forecast of real GDP forecast contained in the Tealbook (formerly, the Greenbook).

Our main result is that the sensitivity of the investment rate to a Fed information shock is greater for more cyclical firms. Our baseline measure of cyclicality is the firm's CAPM beta (i.e., the beta of the firm's stock return with respect to the return of the aggregate stock market). The heterogeneity in investment sensitivity is both statistically significant and economically large. For example, in the two years following a one standard deviation positive CBI shock, a firm whose CAPM beta is one standard deviation greater than the cross-sectional mean increases its capital stock by 2% more than a firm whose CAPM beta is equal to the cross-sectional mean. We find similar results when we use the beta of firm sales growth with respect to GDP growth as an alternate measure of firm cyclicality. Our result that more cyclical firms have a higher sensitivity of the investment rate to a CBI shock is robust to controlling for macroeconomic news released in the run up to Fed announcements, thereby addressing the concern of Bauer and Swanson (2022, 2023).

We obtain our second result from studying revisions in analysts' forecasts of firm fundamentals following a Fed information shock. We find that more cyclical firms have a higher sensitivity of revisions in future earnings-per-share and sales growth forecasts to a CBI shock. For this analysis, we use data from the Institutional Broker's Estimate System (IBES) which contains the forecasts of a large number of analysts for each individual firm. In using the cross-section to identify Fed information effects on analysts' forecasts, our empirical strategy follows the same logic as our analysis of firm investment—if Fed information affects aggregate economic conditions, we expect analysts' forecasts of firm fundamentals of more cyclical firms to have a greater sensitivity to such information.

What do the analyst forecast results add on top of our main investment results? Investment outcomes are realized over several quarters during which other confounding shocks could be present (Nakamura and Steinsson, 2018, p. 1284). IBES analyst forecast data are available at a monthly frequency and allows us to measure expectations of future outcomes over a much shorter window following Fed information shocks. This alleviates the concern regarding other confounding shocks.

Our third result provides evidence that firms' investment response to Fed information is consistent with a profitability channel. Specifically, we find that the profitability (i.e., return on assets) of more cyclical firms have a higher sensitivity to Fed information shocks. In general, changes in firms' investment can be due to either changes in the discount rate used by firms to value investment or due to changes in firm profitability (see, e.g., Kogan and Papanikolaou 2012, equation 17). The existing literature documents many ways in which monetary policy affects investment through the discount rate channel (see, e.g., Bernanke and Gertler 1995 and Christiano et al. 2005). To the best of our knowledge, our paper is the first to document that monetary policy can affect investment through the profitability channel.

We propose a heterogeneous agent New Keynesian (HANK) model to analyze the heterogeneous effect of the Fed information shock on firms and to study the implications of the shock for monetary policy. The model features two deviations from the benchmark New Keynesian framework. First, we assume that firms differ in the cyclicality of their productivity. Second, we assume that the Fed receives news about the future path of aggregate productivity which it then shares with firms and investors.

The CBI shock arises as an equilibrium outcome in our model. For instance, both the level of the aggregate stock market and nominal interest rates increase if the Fed receives news of a sufficiently large increase in future aggregate productivity. That is, a positive CBI shock is realized. The nominal interest rate increases because of an increase in inflation due to the impending economic boom and also because of an increase in the real interest rate driven by expectations of higher growth. The stock market rallies if the effect of future cash flows from higher productivity more than offsets the negative effect of higher interest rates.

Our model predicts more cyclical firms to have a higher sensitivity of investment rates to a CBI shock. This is because a positive CBI shock, implies a greater increase in future productivity for more cyclical firms. These more cyclical firms therefore optimally increase their investment rate by a greater amount compared to less cyclical firms. These model implications are in line with our empirical findings.

At the aggregate level, our model implies a muted response of inflation and output growth to a Fed Funds rate increase when Fed announcements signal higher than average future productivity. Quantitatively, our model predicts that following Fed announcements which do not lead to revisions in future productivity, a 25 basis point increase in the Fed Funds rate results in a 1% decline in inflation. In contrast, if Fed announcements lead to an upward revision in future productivity by 0.8%, the same 25 basis point increase in the Fed Funds rate results in a 0.2% *increase* in inflation. Our model therefore provides a quantitative framework to rationalise the Fed Chair Powell's recent comment in his August 25, 2023 Jackson Hole speech that, "[a]dditional evidence of persistently above-trend growth could put further progress on inflation at risk and could warrant further tightening of monetary policy."

Related Literature

Our paper contributes to the emerging literature that analyzes if the Fed's private information about economic conditions revealed through FOMC announcements impacts the real economy. Evidence that this Fed information effect changes professional forecasters' expectations of economic conditions has been provided by Romer and Romer (2000), Campbell et al. (2012), Melosi (2017), and Nakamura and Steinsson (2018). Similarly, Jarociński and Karadi (2020) and Cieslak and Schrimpf (2019) show that central bank announcements contain a news component about future economic growth and also financial risk premia by analyzing interest rates and the aggregate stock market. Recent work by Bauer and Swanson (2022, 2023) has questioned the evidence in Romer and Romer (2000), Campbell et al. (2012), and Nakamura and Steinsson (2018) regarding the effect of Fed information on inflation, unemployment, and real GDP forecasts of professional forecasters, respectively. Specifically, Bauer and Swanson (2022, 2023) show that the evidence in these papers is not robust to controlling for news released prior to Fed announcements.

While the analysis in these papers use aggregate data, we use firm-level evidence to provide support for the Fed information effect. The large cross-section increases the statistical power with which Fed information effects can be detected. Indeed, we find evidence consistent with Fed information effects even after accounting for the concerns in Bauer and Swanson (2022, 2023).

Our paper also contributes to the growing literature on Heterogeneous Agent New Keynesian (HANK) models which studies the effect of monetary policy shocks in the presence of heterogeneous households (see, e.g., Kaplan et al. 2018) or heterogeneous firms (see, e.g., Ottonello and Winberry 2020). Because we focus on firm investment, we emphasize firm-level heterogeneity. Unlike Ottonello and Winberry (2020), who study the transmission of monetary policy shocks in the presence of financial frictions, firms in our model do not face financial frictions. Instead, we emphasize heterogeneity in the firm cyclicality.

There is also a large literature that provides evidence of central bank policy surprises affecting asset prices. These include Bernanke and Kuttner (2005), Savor and Wilson (2014), Gorodnichenko and Weber (2016), Chava and Hsu (2020), Cieslak and Pang (2021), Leombroni et al. (2021), Ai et al. (2022), and Pflueger and Rinaldi (2022). In contrast to these papers, we focus on the real effects of monetary policy surprises.

2 Empirical evidence

In this section, we provide three pieces of firm-level evidence for the Fed information effect. First, the investment rate sensitivity to Fed information is greater for more cyclical firms. Second, revisions in analyst forecasts of firm fundamentals following Fed information shocks are greater for more cyclical firms. Third, the investment response to Fed information is consistent with a profitability channel in which positive Fed information forecasts larger increases in profitability for more cyclical firms.

2.1 Data

Our sample period is January 1990—June 2019. We describe our data sources and construction below.

Monetary policy shocks. We use the measure of monetary policy surprise (henceforth "MPS shock") from Bauer and Swanson (2022). They compute the surprise as the first principal component of the changes in four short-term Eurodollar futures contracts in a 30-minute window around FOMC announcements; this construction is similar to the one from Nakamura and Steinsson (2018).

Since FOMC announcements can simultaneously convey information about monetary policy as well as the Fed's assessment of future economic outlook, MPS shocks summarize the combined effects of conventional monetary shocks and Fed information effects. In order to focus on the Fed information effect, we use the Jarociński and Karadi (2020) (henceforth "JK") decomposition of monetary policy shocks. Specifically, JK decomposes a monetary policy shock into a central bank information shock (henceforth "CBI shock") and a conventional monetary policy shock (henceforth "MP shock", not to be confused with a MPS shock). They identify these two shocks through the comovement between the S&P 500 index and the 3-month Fed funds futures over a 30-minute window around FOMC announcements—CBI and MP shocks are associated with positive and negative comovements between the S&P 500 and interest rates, respectively. The logic of this identification scheme is that in the absence of positive news regarding future economic prospects, an interest rate increase would lead to a decline in the stock market (Bernanke and Kuttner, 2005).[1] We point our readers to Jarociński and Karadi (2020) for evidence that CBI shocks positively forecast future economic

[1]JK implement this idea using a structural vector autoregression where the CBI and MP shocks are identified using sign restrictions.

conditions.

Bauer and Swanson (2022, 2023) argue that it is important to control for other sources of news in the run up to FOMC announcements in order to assess the existence of Fed information effects. They show that the findings in Romer and Romer (2000) and Nakamura and Steinsson (2018) no longer hold after taking other sources of news into account. Therefore, we control for the six macroeconomic and financial variables from Bauer and Swanson (2022). These variables are (1) the most recent nonfarm payroll surprise, (2) the log change in nonfarm payrolls over the past 12 months, (3) the log change in the S&P 500 from 13 weeks prior to the FOMC announcement to the day before the announcement, (4) the 13 week changes in the slope of the yield curve, (5) the 13 week log change in the Bloombeg BCOM commododity price index, and (6) the Bauer and Chernov (2024) option-implied skewness of the 10-year Treasury yield the day before the FOMC announcement.

Our analysis for realized firm-level investment (Section 2.2) and profitability (Section 2.4) are conducted at a quarterly frequency. We follow the literature and construct quarterly monetary shocks by summing up the meeting level monetary shocks within each quarter. In computing this sum, we follow Nakamura and Steinsson (2018) and focus only on scheduled FOMC meetings.[2] Our analysis of revisions in analyst forecast of firm fundamentals (Section 2.3) are at the FOMC meeting level so that time-aggregation of monetary shocks is not necessary.

Firm-level outcomes. We use quarterly financial data from Compustat to measure firm-level variables. We exclude financial firms (sic code from 6000 to 6999) and utility firms (sic code from 4900 to 4999). We merge stock price data from CRSP with Compustat data, and

[2]The quarterly shocks we obtain is slightly different from the quarterly data provided by Jarociński and Karadi (2020). This is because Jarociński and Karadi (2020) also include unscheduled FOMC meetings when reporting their quarterly shock. Our results remain robust if we directly use their quarterly shocks.

keep firms with a share code of 10 or 11 and an exchange code of 1, 2, or 3.

We measure the investment rate of firms as the log change in capital stock which we construct using the perpetual inventory method following Ottonello and Winberry (2020). For all our analysis, we include four firm-level control variables: the logarithm of total asset, book leverage (current debt *dlcq* plus long-term debt *dlccq* divided by total asset), Tobin's Q (total asset minus book equity *ceqq* plus market equity $cshoq \times prccq$ divided by total asset), and cash flow (income before extraordinary items *ibd* plus depreciation and amortization *dbq* divided by lagged total asset). To compute firms' future annual realized profitability, we sum up the quarterly operating income before depreciation (*oibdpq*) in the first year (or second or third year, depending on the horizon) and divide it by the corresponding lagged total asset.

Our baseline measure of a firm's cyclicality is its CAPM beta. We estimate the CAPM beta of each firm as the loading of the excess monthly return of this firm on the excess monthly return of the market over our entire sample period. We use the market-value weighted portfolio of all stocks listed in CRSP as our proxy for the market; we use the return on the 1-month Treasury bill as our measure of the risk-free rate. Our alternate cyclicality measure is sales beta, measured by regressing quarterly sales growth on GDP growth. We prefer CAPM beta over sales beta because it is better estimated—we have two times more observations for the estimation of CAPM betas using monthly stock return data compared to the estimation of sales betas using quarterly sales data.

Firm-level analyst forecasts. We make use of monthly summary files from the Institutional Broker's Estimate System (IBES) to measure revisions in equity analysts' forecasts of firm fundamentals following each scheduled FOMC announcement. To do so, we match each FOMC scheduled announcement to the subsequent IBES monthly file (the IBES files are typically released during the middle of each month). In order to ensure that equity analysts have had sufficient time to digest the implications of a FOMC announcement on a firm, we ignore IBES files released within a week of an FOMC announcement and use the next available IBES file. For example, we use the May 18, 2017 IBES release for the May 3, 2017 FOMC meeting. We ignored the March 17, 2016 IBES release for the March 16, 2016 FOMC meeting and instead use the April 14, 2016 IBES release.

The IBES files list the revision in analyst forecasts for a number of firm variables. This is done for each analyst covering a firm. We focus on the two most populated measures from IBES: earnings per share (EPS) and sales. We focus on one-year ahead forecasts because, depending on the timing of a FOMC meeting, the current-year forecast may include months that have already passed. To measure revisions in analyst forecasts of EPS following an FOMC announcement, we use the net upward revision in EPS, UpRevEPS, defined as the difference between the number of upward and downward revisions in analyst forecasts of EPS divided by the total number of EPS forecasts. The definition for the net upward revision in analyst forecasts of sales, UpRevSales, is analogous.

We report all summary statistics in Table 1.

2.2 Fed information effect and firm-level investment response

In this section, we provide evidence that Fed information affects firms' investment. Specifically, we show that the investment response following CBI shocks is larger for more cyclical firms.

We investigate variants of the following panel regression:

$$\Delta logk_{i,t-1\to t-1+h} = \boldsymbol{\delta}'_{m,h}\left(\beta_i \times \boldsymbol{m}_t\right) + \boldsymbol{\gamma}'_h \boldsymbol{X}_{i,t-1} + \eta_i + \theta_{s,t} + \epsilon_{i,t}. \tag{1}$$

The dependent variable $\Delta logk_{i,t-1\to t-1+h} \equiv \log k_{i,t-1+h} - \log k_{i,t-1}$ is the log change in firm

Table 1: Summary Statistics. This table reports summary statistics for variables used in our analysis. The sample period is 1990—2019.

	N	Mean	Median	Std Dev
Panel A: Firm-Level Variables				
$\Delta log k_{i,t-1\to t-1+8}$	331,364	0.1010	0.0223	0.5288
UpRevEPS	427,161	-0.0252	0	0.3642
UpRevSales	303,517	-0.0125	0	0.4019
$\text{Profit}_{i,t\to t+3}$	312,524	0.0121	0.1102	0.4308
$\text{Profit}_{i,t+4\to t+7}$	304,780	0.0111	0.1077	0.4240
$\text{Profit}_{i,t+8\to t+11}$	281,431	0.0171	0.1086	0.4013
Log(asset)	331,364	5.0475	4.9717	2.2755
Book leverage	331,364	0.2368	0.1702	0.3020
Tobin's Q	331,364	2.5589	1.6150	3.1342
Cash flow	331,364	-0.0134	0.0185	0.1269
CAPM β	9,338	1.2199	1.1350	0.8882
Sales β	9,186	0.8488	0.5558	3.9318
Panel B: Meeting-Level Variables				
MPS	236	0.0026	0.0085	0.0511
CBI	236	-0.0051	-0.0020	0.0284
MP	236	-0.0034	-0.0012	0.0473
Nonfarm Payrolls	236	-0.1635	-0.06	0.9646
Empl. Growth (12m)	236	1.1090	1.5991	1.5842
Δ log S&P 500 (3m)	236	0.0178	0.0316	0.0713
Δ Slope (3m)	236	-0.01	-0.635	0.4441
Δ log Comm. Price (3m)	236	0.0105	0.0134	0.0780
Treasury Skewness	236	0.1239	0.1471	0.2842
Panel C: Quarterly-Level Variables				
MPS	118	0.0052	0.0139	0.07
CBI	118	-0.0101	-0.0041	0.0427
MP	118	-0.0069	-0.0060	0.0588
Nonfarm Payrolls	118	-0.3269	-0.27	1.4387
Empl. Growth (12m)	118	2.2181	3.0294	3.2866
Δ log S&P 500 (3m)	118	0.0355	0.0529	0.1303
Δ Slope (3m)	118	-0.02	-0.0827	0.8095
Δ log Comm. Price (3m)	118	0.0211	0.0305	0.1401
Treasury Skewness	118	0.2479	0.2539	0.5503

i's capital stock, starting from the end of quarter $t-1$ to the end of quarter $t-1+h$. We consider two variants for the monetary shock $\boldsymbol{m}_t$ in quarter t: either the MPS shock (i.e., $\boldsymbol{m}_t = MPS_t$) or the JK decomposition of a monetary shock (i.e., $\boldsymbol{m}_t = [CBI_t \; MP_t]'$). The key coefficients of interest are the slope coefficients for the interaction terms between monetary shocks and firm cyclicality β_i (which we measure using a firm's CAPM beta in our baseline regressions). For example, these slope coefficients are $\boldsymbol{\delta}_{m,h} = [\delta_{CBI,h} \; \delta_{MP,h}]'$ when $\boldsymbol{m}_t = [CBI_t \; MP_t]'$. In the presence of Fed information effects, we would expect the investment response of more cyclical firms to be stronger following a FOMC announcement that conveys positive news regarding future economic prospects; this would translate into a positive coefficient $\delta_{CBI,h}$.

We include a number of controls in regression (1). First, $X_{i,t-1}$ includes the following lagged firm-level controls at time $t-1$ that may affect firm investment: logged total asset, book leverage, Tobin's Q, and cash flow. We add a firm fixed effect η_i to control for firm-level time-invariant factors that matter for firm investment. We add sector s by quarter t fixed effects $\theta_{s,t}$ to control for common sector-level shocks that affect firm investment.[3] Note that in specification (1), the CAPM beta β_i is absorbed by the firm fixed effect η_i, while the monetary shock(s) $\boldsymbol{m}_t$ are absorbed by the sector by quarter fixed effects $\theta_{s,t}$. As a robustness check, we also report results when we additionally include interaction terms between firm cyclicality and all six economic and financial news variables from Bauer and Swanson (2022).

Table 2 reports the results for regression (1) for $h = 8$ quarters; the standard errors are clustered at the firm and year-quarter level. In column (1) of Table 2, we begin by taking MPS to be the only shock in regression (1). We see that the coefficient on the interaction

[3]We follow Ottonello and Winberry (2020, footnote 3) in defining the sectors based on SIC codes: agriculture, forestry, and fishing; mining, construction; manufacturing; transportation communications, eletric, gas, and sanitation services; wholesale trade; retail trade; and services. Finance, insurance, real estate, and utilities are excluded.

Table 2: Firm cyclicality and the investment response to monetary shocks. This table reports the results for regression (1) with $h = 8$ quarters. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Standard errors are clustered at the firm and year-quarter level and are reported in parentheses.

	(1)	(2)	(3)	(4)
MPS $\times\ \beta$	0.211***	0.082		
	(0.055)	(0.054)		
CBI $\times\ \beta$			0.543***	0.395***
			(0.103)	(0.096)
MP $\times\ \beta$			0.031	-0.041
			(0.063)	(0.053)
Observations	331,364	331,364	331,364	331,364
R^2	0.349	0.350	0.350	0.351
Firm-level Controls	✓	✓	✓	✓
Economic News $\times\ \beta$		✓		✓
Firm FE	✓	✓	✓	✓
Sector×Time FE	✓	✓	✓	✓

term between MPS and CAPM beta $\delta_{MPS,8}$ is positive and statistically significant at the 1% level. That is, the investment of more cyclical firms respond more strongly following a positive MPS shock which is consistent with the Fed information effect.

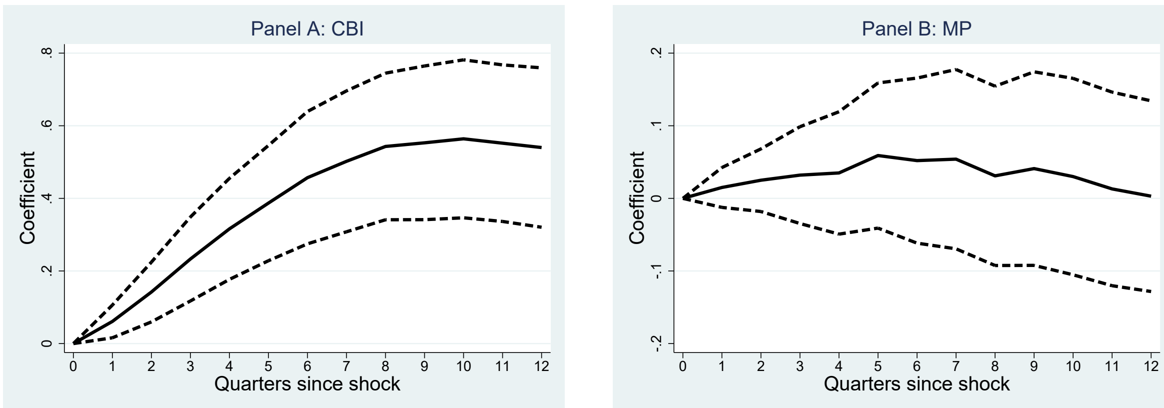
In column (2) of Table 2, we additionally include interactions between all six financial and macroeconomic news variables from Bauer and Swanson (2022) and CAPM beta. As argued by Bauer and Swanson (2022, 2023), it is important to control for news just prior to FOMC announcements when assessing the presence of Fed information effects. We see that the coefficient on the interaction term between MPS and CAPM beta is no longer significant when controlling for news. This finding is consistent with the results from Bauer and Swanson (2022, 2023) that challenge the presence of the Fed information effect. Specifically, in the context of aggregate time-series variables, they no longer find evidence for Fed information effects following an MPS shock after controlling for news.

Next, we demonstrate the importance of decomposing monetary shocks into CBI and MP components when assessing the presence of Fed information effects. Column (3) of Table 2 is our baseline result in which a monetary shock is decomposed into CBI and MP components in regression (1). We see that the coefficient for the interaction between CBI shocks and CAPM beta $\delta_{CBI,8}$ is positive and statistically significant at the 1% level. This implies that more cyclical firms have higher investment rate sensitivity to CBI shocks compared to less cyclical firms. The difference in the investment response is economically large. For instance, following a positive one standard deviation CBI shock, a firm whose CAPM beta is one standard deviation above the mean has an investment rate that is 2.1 percentage points higher than a firm whose CAPM beta is equal to the sample mean. In contrast, the coefficient $\delta_{MP,8}$ for the interaction term between MP shocks and CAPM beta is insignificant; that is, there is no cross-sectional difference in the investment rate response to an MP shock between high and low CAPM beta firms. In Section 4, we demonstrate that these patterns in the cross-sectional response of firm investment to CBI and MP shocks is predicted by our HANK model in which there is heteregeneity in firm cyclicality.

In column (4) of Table 2, we repeat the analysis from column (3) but additionally include interactions between all six financial and macroeconomic news variables from Bauer and Swanson (2022) and CAPM beta. We see that $\delta_{CBI,8}$ remains positive and statistically significant at the 1% level although its point estimate is smaller when we control for news (0.4 vs. 0.54). The estimate for $\delta_{MP,8}$ remains insignificant.

Dynamic investment response. While the results above are for $h = 8$ quarters, in Figure 1 we report estimates for the coefficients $\delta_{CBI,h}$ and $\delta_{MP,h}$ for our baseline specification

Figure 1: Dynamic investment response to monetary shocks. The left and right panels plot estimates of $\delta_{CBI,h}$ and $\delta_{MP,h}$, respectively, for $h = 1, 2, \cdots, 12$ quarters. We use our baseline version of regression (1) corresponding to column (3) of Table 2. The solid line plots the point estimates while the dashed lines show 95% confidence intervals.



(i.e., column (3) of Table 2) for $h = 1, 2, \cdots, 12$ quarters. The left panel shows a large and persistent difference in the investment response to a CBI shock between low and high CAPM beta firms. The interaction coefficient $\delta_{1,h}$ increases from $h = 1$ to $h = 8$ quarters and remains flat to $h = 12$ quarters. In contrast, from the right panel we see that $\delta_{2,h} = 0$ over this range of h; that is, there is no difference in the investment rate response between high and low CAPM beta firms to an MP shock over 12 quarters following an MP shock.

Robustness. Besides being robust to the inclusion of other sources of news prior to FOMC meetings, our main result from column (3) of Table 2 holds for a number of additional robustness checks. We describe them below.

First, because a significant portion of the period in our sample includes the period following the Great Recession which featured zero nominal short rates and unconventional monetary policy, we repeat our analysis over the precrisis sample period 1990-2008. Column (1) of Table 3 shows that our results remain unchanged. In fact, the pre-2008 period appears to show a greater heterogeneity in investment response to a CBI shock—the point estimate of

Table 3: Robustness checks. This table reports robustness checks for our main result from column (3) of Table 2. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Standard errors are clustered at the firm and year-quarter level and are reported in parentheses.

	Pre 2008 (1)	Sales beta (2)	Beta dummy (3)	Ctrl lag inv (4)
CBI $\times$ β	0.686***	0.055**	0.493***	0.497***
	(0.128)	(0.023)	(2.263)	(0.092)
MP $\times$ β	-0.009	-0.000	0.053	0.035
	(0.069)	(0.012)	(0.060)	(0.057)
Observations	223,854	320,431	331,364	311,585
R^2	0.392	0.364	0.349	0.349
Firm-level Controls	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓
Sector×Time FE	✓	✓	✓	✓

the coefficient $\delta_{CBI,8}$ is 0.686 in the pre-2008 period compared to 0.543 in the full sample.

Second, we repeat our analysis using sales beta as an alternative measure of firm cyclicality. The results are shown in column (2) of Table 3. The coefficient $\delta_{CBI,8}$ remains positive and statistically significant at the 5% level. The point estimate implies that following a positive one standard CBI shock, a firm whose sales beta is one standard deviation above the mean has an investment rate that is 0.9 percentage points higher than a firm whose sales beta is equal to the sample mean. This difference is smaller compared to the difference implied by our baseline results based on CAPM betas, likely because sales beta is a noisier measure of cyclicality compared to CAPM beta.

Third, we replace the continuous variable β with the dummy variable β_{p50} for the interaction term in regression (1) (we set β_{p50} to 1 if a firm's CAPM beta is above the median and zero otherwise). We do so in order to alleviate the influence of outliers in β on our estimates. The results are reported in column (3) of Table 3. The point estimate implies that following a one-standard deviation CBI shock, a firm above the median of the CAPM beta distribution increases its investment rate by 2.1 percentage points more than that of a firm below the median of the CAPM beta distribution.

Fourth, we additionally control for lagged investment over the four quarters prior to the FOMC announcement quarter. We do so because investment planning takes time which means that firms' capital accumulation after an FOMC announcement can be due to already-made plans and not due to information conveyed by the FOMC announcement. The results are shown in column (4) of Table 3. The coefficient $\delta_{CBI,8}$ remains positive and significantly significant, and the point estimate remains similar.

Throughout all of our robustness checks, note that the coefficient $\delta_{MP,8}$ remains insignificant as in our main result from column (3) of Table 2.

2.3 Revisions in analyst forecasts of firm fundamentals

In this section, we provide further evidence for the Fed information effect based on revisions in analyst forecasts of firm fundamentals following FOMC announcements. We show that the revisions are stronger for more cyclical firms following positive CBI shocks, in line with our investment results from Section 2.2.

We investigate the following panel regression:

$$\text{UpRevX}_{i,t} = \widehat{\delta}_{CBI}(\beta_i \times CBI_t) + \widehat{\delta}_{MP}(\beta_i \times MP_t) + \boldsymbol{\gamma}'\boldsymbol{X}_{i,t-1} + \eta_i + \theta_{s,t} + \epsilon_{i,t}. \tag{2}$$

The dependant variable is either the net upward revision in one-year ahead analyst forecasts of EPS (UpRevEPS) or sales (UpRevSales) following an FOMC meeting. We focus on EPS and sales since these are the two most populated variables in IBES. The remaining specification for regression (2) is identical to that of our baseline investment regression (whose results are reported in column (3) of Table 2). The data allows us to implement regression (2) at

Table 4: Revisions in analyst forecasts of firm fundamentals following FOMC announcements. This table reports the results for regression (2). *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Standard errors are clustered at the firm and year-quarter level and are reported in parentheses.

	UpRevEPS	UpRevSales
	(1)	(2)
CBI $\times$ β	0.255***	0.373***
	(0.085)	(0.086)
MP $\times$ β	-0.014	0.028
	(0.039)	(0.044)
Observations	427,161	303,594
R^2	0.079	0.093
Firm-level Controls	✓	✓
Firm FE	✓	✓
Sector$\times$Time FE	✓	✓

the FOMC meeting-level frequency which has the advantage of avoiding noise induced by time-aggregation.

Columns (1) and (2) of Table 4 report the results for analyst revisions of EPS and sales, respectively. In both cases, we see that the coefficient $\widehat{\delta}_{CBI}$ is positive and statistically significant at the 1% level. That is, following a positive CBI shock, analysts upward revise their one-year ahead forecast of EPS and sales by a greater amount for more cyclical firms compared to low beta firms. Analogous to our earlier investment regressions, the coefficient $\widehat{\delta}_{MP}$ is insignificant. That is, MP shocks do not generate meaningful cross-sectional differences in revisions of analyst forecasts for EPS and sales.

2.4 Profitability channel

In Section 2.2, we showed that the sensitivity of a firm's investment response to CBI shocks depends on the firm's cyclicality. In this section, we provide evidence that this dependance

Table 5: Firm cyclicality and realized profitability following monetary shocks. This table reports the results for regression (3) for $n \in \{1, 2, 3\}$ years. *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Standard errors are clustered at the firm and year-quarter level and are reported in parentheses.

	$n = 1$ year	$n = 2$ year	$n = 3$ year
	(1)	(2)	(3)
CBI $\times$ β	0.021	0.094***	0.081**
	(0.032)	(0.033)	(0.036)
MP $\times$ β	0.024	-0.041**	-0.003
	(0.020)	(0.018)	(0.021)
Observations	341,604	307,663	283,926
R^2	0.775	0.703	0.699
Firm-level Controls	✓	✓	✓
Firm FE	✓	✓	✓
Sector$\times$Time FE	✓	✓	✓

is consistent with a profitability channel in which positive Fed information forecasts larger increases in profitability for more cyclical firms.

Our evidence is based on the following panel regression:

$$\text{Profit}_{i,t-4+4n \to t-1+4n} = \widehat{\delta}_{CBI}(\beta_i \times CBI_t) + \widehat{\delta}_{MP}(\beta_i \times MP_t) + \boldsymbol{\gamma}' \boldsymbol{X}_{i,t-1} + \eta_i + \theta_{s,t} + \epsilon_{i,t}. \quad (3)$$

The dependant variable $\text{Profit}_{i,t-4+4n \to t-1+4n}$ is the realized annual profitability in the nth year following quarter t monetary shocks, where profitability is measured as a firm's return on assets. The remaining specification is identical to that of our baseline investment regression.

Table 5 reports the results for the profitability regression (3). Columns (1) through (3) show the results for $n = 1$ through $n = 3$ years, respectively. We see that $\widehat{\delta}_{CBI}$ is insignificant for the first year and becomes positive and statistically significant in the second at third year (with significance at the 1% and 5% levels, respectively). The magnitude of the effect is economically significant. For instance, in the second year following a positive one standard deviation CBI shock, a firm whose CAPM beta is one standard deviation above the mean has a profitability that is 0.36 percentage points higher than a firm whose CAPM beta is equal to the mean.

Similar to our investment results, the coefficient $\widehat{\delta}_{MP}$ for the interaction term between CAPM beta and MP shocks is less significant compared to the $\widehat{\delta}_{CBI}$. Specifically, $\widehat{\delta}_{MP}$ is insignificant for $n = 1$ and $n = 3$ years, while it is negative and significant at the 5% level for $n = 2$ years.

3 Model

In this section, we develop a heterogeneous agent New Keynesian (HANK) model featuring heterogeneity in firm betas to interpret our evidence and study its aggregate implications. The environment consists of three components: (1) an investment component that captures heterogeneity in firms' responses to monetary policy, (2) a New Keynesian component that generates a Phillips curve, and (3) a representative household which closes the model.

3.1 Investment component

Time t is continuous and the horizon is infinite. There is no aggregate uncertainty—we study the transition path of the economy following an unexpected monetary shock.

The investment component of the environment consists of a unit mass of firms that we refer to as wholesalers. Each wholesaler $i \in [0, 1]$ accumulates capital $K_i(t)$ and hires labor $N_i(t)$ at a real wage rate of $w(t)$ to produce an undifferentiated wholesale good. The production function is

$$y_i(t) = e^{\beta_i z(t)} K_i(t)^\alpha N_i(t)^{1-\alpha}$$

where $z(t)$ denotes aggregate productivity and we refer to β_i as the "productivity beta" of firm i. Retail firms from the New Keynesian block of the environment (described later in Section 3.2) purchase wholesale goods at a per unit price of $p_w(t)$ in real terms.

Wholesalers are heterogeneous in their productivity betas whose cross-sectional distribution is given by $\beta_i \sim \Gamma$ with $\int \beta d\Gamma(\beta) = 1$ so that the average beta is one across firms. Cross-sectional differences in productivity betas give rise to differences in productivity which, in turn, lead to differences in firm policies and firms' responses to monetary shocks.

Wholesalers accumulate capital according to the law of motion

$$dK_i(t) = [\iota_i(t) - \delta]K_i(t)dt \tag{4}$$

where $\iota_i(t) \equiv I_i(t)/K_i(t)$ is the investment rate and δ is the rate of capital depreciation. Investments in capital are subject to quadratic adjustment costs so that $\left[\iota_i(t) + \frac{\kappa}{2}\iota_i(t)^2\right] K_i(t)$ is the total cost associated with an investment rate of $\iota_i(t)$.

Wholesalers are subject to Poisson exit shocks that arrive at rate χ. Capital fully depreciates upon arrival of the exit shock and the affected wholesaler exits. Exiting wholesalers are replaced by newly entering wholesalers so that the total mass of wholesalers remain constant. Newly entering wholesalers are endowed with an initial capital of K_{init}.

Wholesalers' problem. We now drop the subscript i in referencing wholesalers in order to avoid clutter. Wholesalers' labor demand is determined by solving the static labor choice problem

$$\Phi(z(t), p_w(t), w(t); \beta)K(t) \equiv \max_{N(t)} p_w(t)e^{\beta z(t)}K(t)^\alpha N(t)^{1-\alpha} - w(t)N(t).$$

The solution implies a labor demand of $N(t, K; \beta) = K(t)n\left(z(t), p_w(t), w(t); \beta\right)$ where

$$n(z(t), p_w(t), w(t); \beta) = \left[\frac{(1-\alpha)p_w(t)e^{\beta z(t)}}{w(t)}\right]^{1/\alpha} \tag{5}$$

is the labor demand to capital ratio and

$$\Phi(z(t), p_w(t), w(t); \beta) = \alpha \left[p_w(t) e^{\beta z(t)}\right]^{1/\alpha} \left(\frac{w(t)}{1-\alpha}\right)^{1-1/\alpha} \tag{6}$$

is firm profitability as measured by the return on assets (ROA).

Wholesalers choose their investment policy to maximize the present value of future dividends

$$V(t, K; \beta) = \max_{\{\iota(s): s \geq t\}} \mathbb{E}\left[\int_t^{\tau_{exit}} e^{-\int_t^s r(u)du} \left[\Phi(z(s), p_w(s), w(s); \beta) - \iota(s) - \frac{\kappa}{2}\iota(s)^2\right] K(s) ds\right] \tag{7}$$

subject to the law of motion (4). Here, the expectation is over the time of exit τ_{exit}, and the paths for the real interest rate $r(t)$, the wholesale price $p_w(t)$, and wages $w(t)$ are all taken as given by the wholesaler. In Appendix B.1, we show that the value function scales according to $V(t, K; \beta) = K v(t; \beta)$ where $v(t; \beta)$ satisfies

$$[r(t) + \chi] v(t; \beta) = \max_{\iota} \Phi(z(t), p_w(t), w(t); \beta) - \iota - \frac{\kappa}{2}\iota^2 + v_t(t; \beta) + (\iota - \delta) v(t; \beta). \tag{8}$$

The first order condition for optimal investment is

$$\iota(t; \beta) = \kappa^{-1}\left[v(t; \beta) - 1\right]. \tag{9}$$

Cross-sectional distribution of capital. Let $f(t, K; \beta)$ denote the cross-sectional distribution of capital for wholesalers with productivity beta β at time t. This distribution evolves according to the Kolmogorov forward equation (KFE)

$$f_t(t, K; \beta) = -\frac{\partial}{\partial K}\left[\left(\iota(t; \beta) - \delta\right) K f(t, K; \beta)\right] + \chi\left[\delta(K; K_{init}) - f(t, K; \beta)\right] \tag{10}$$

where $\delta(\cdot; K_{init})$ denotes the Dirac delta function with point mass at K_{init}. The first term on the right hand side of the KFE accounts for changes in capital due to investment while the second term accounts for changes in capital as a result of entry and exit.

3.2 New Keynesian component

This component of the environment generates a New Keynesian Phillips curve that relates nominal variables to the real economy.

Retailers and final good producer. There is a unit mass of retailers indexed by $j \in [0,1]$. Each retailer j produces a differentiated intermediate good $y_j(t)$ using the undifferentiated wholesale good as the only input. That is, retailer j produces according to $y_j(t) = \widetilde{y}_j(t)$ where $\widetilde{y}_j(t)$ is the quantity of wholesale inputs used by retailer j.

A representative final good producer acts competitively and combines intermediate goods into the final good according to

$$Y(t) = \left(\int_0^1 y_j(t)^{1-\epsilon^{-1}}\,dj\right)^{\frac{1}{1-\epsilon^{-1}}}$$

where $\epsilon > 1$ is the elasticity of substitution across intermediate goods. The final goods aggregator implies a demand of

$$y_j(t) = Y(t)\left(\frac{p_j(t)}{P(t)}\right)^{-\epsilon} \tag{11}$$

for intermediate good j when good j has a nominal price of $p_j(t)$, where

$$P(t) = \left(\int_0^1 p_j(t)^{1-\epsilon}\,dj\right)^{\frac{1}{1-\epsilon}}$$

is the price index.

New Keynesian Phillips curve. Retailers are monopolistically competitive and set retail prices subjective to quadratic adjustment costs (Rotemberg, 1982). Specifically, retailer j chooses the path of $p_j(t)$ to solve

$$\max \int_0^\infty e^{-\int_0^t r(s)ds}\Pi_j(t)\,dt \tag{12}$$

subject to the demand curve (11), where $\Pi_j(t) = \frac{p_j(t)}{P(t)} y_j(t) - p_w(t) y_j(t) - \frac{1}{2}\theta \left(\frac{p_j'(t)}{p_j(t)}\right)^2 Y(t)$ is retailer j's real dividends and $\theta > 0$ is the price adjustment cost parameter.

We focus on a symmetric equilibrium in which $p_j(t) = P(t)$ and $y_j(t) = Y(t)$ for all j and t. Let $\pi(t) = p_j'(t)/p_j(t) = P'(t)/P(t)$ denote the rate of inflation. In Appendix B.2, we show that the solution to retailers' optimal price setting problem (12) implies the following New Keynesian Phillips curve:

$$\left[r(t) - \frac{Y'(t)}{Y(t)}\right] \pi(t) = \pi'(t) + \frac{\epsilon}{\theta} \left[p_w(t) - p_w^\star\right] \tag{13}$$

where $p_w^\star = (\epsilon - 1)/\epsilon$.

3.3 Representative household

The representative household supplies labor and owns all firms in equilibrium. The representative household chooses consumption C and labor N to maximize utility

$$\int_0^\infty e^{-\rho t} \left(\frac{C(t)^{1-\gamma}}{1-\gamma} - \varphi N(t)\right) dt,$$

where ρ is the household's subjective discount rate, $1/\gamma$ is the intertemporal elasticity of substitution, and $\varphi > 0$ is the disutility of labor. The household's saving in bonds $B(t)$ is subject to the budget constraint

$$dB(t) = \left[r(t)B(t) - C(t) + w(t)N(t) + \Pi(t)\right] dt$$

where $\Pi(t)$ denotes the total dividends, in real terms, that the household receives.

In Appendix B.3, we show that the solution to the household's utility maximization problem is characterized by the first order condition for labor supply,

$$w(t)C(t)^{-\gamma} = \varphi, \tag{14}$$

and the consumption Euler equation,

$$\frac{C'(t)}{C(t)} = \frac{r(t) - \rho}{\gamma}. \tag{15}$$

3.4 Monetary authority

The monetary authority sets the nominal interest rate $i(t)$ according to a Taylor rule:

$$i(t) = \rho + \phi_\pi \pi(t) + \varepsilon^m(t) \tag{16}$$

where $\phi_m > 1$ and $\varepsilon^m(t)$ is a deterministic monetary policy shock (which we describe in Section 3.6). In addition, nominal and real interest rates are linked by the Fisher equation

$$i(t) = r(t) + \pi(t). \tag{17}$$

3.5 Equilibrium

Given paths for $z(t)$ and $\varepsilon^m(t)$, an equilibrium consists of paths for (1) prices $i(t)$, $r(t)$, $\pi(t)$, $w(t)$, and $p_w(t)$, (2) wholesalers' policies $\iota(t;\beta)$, and (3) household policies $C(t)$ and $N(t)$ such that: (i) wholesalers' policies solve problem (8) taking price paths as given, (ii) household policies satisfy the first-order condition for labor supply (14) and the consumption Euler equation (15) taking price paths as given, (iii) price paths satisfy the New Keynesian Phillips curve (13), the Taylor rule (16), and the Fisher equation (17), (iv) the labor market clears: $N(t) = \int\int n\left(z(t), p_w(t), w(t); \beta\right) K f(t, K; \beta)\, dK d\Gamma(\beta)$, (v) the final good market clears: $C(t) + I(t) + \frac{1}{2}\theta\pi(t)^2 Y(t) = Y(t)$, where aggregate investment and aggregate output equal $I(t) = \int\int \left(\iota(t;\beta) + \frac{\kappa}{2}\iota(t;\beta)^2\right) K f(t, K; \beta)\, dK d\Gamma(\beta)$ and $Y(t) = \int\int n\left(z(t), p_w(t), w(t); \beta\right)^{1-\alpha} K f(t, K; \beta)\, dK d\Gamma(\beta)$, respectively, and (vi) the bond market clears: $B(t) = 0$.

3.5.1 Steady state.

In a steady state equilibrium, all shocks are switched off and all policies and aggregate variables are constant over time. As a result, the steady state inflation rate π_{ss}, nominal interest rate i_{ss}, real interest rate r_{ss}, and wholesale prices $p_{w,ss}$ are given by $\pi_{ss} = 0$, $i_{ss} = \rho$, $r_{ss} = \rho$, $p_{w,ss} = p_w^\star$, respectively. We characterize steady state wages w_{ss} and investment rate ι_{ss} in Appendix C.1.

We additionally normalize steady state productivity to $z_{ss} \equiv 0$.[4] This normalization implies that all wholesalers have identical policies and value to capital ratios in steady state, regardless of their productivity betas. That is, labor demand (5), investment (9), and firm value (8) are all independent of β_i in steady state. Productivity betas do, however, affect wholesalers' policies and firm values in response to shocks.

3.6 Monetary shocks and stock market response

We consider two types of monetary shocks: (1) a shock $\varepsilon^m(t)$ to the Taylor rule (16), and (2) a shock to the future path of productivity $z(t)$. We study the equilibrium effects of these two shocks on interest rates and the aggregate stock market. In Section 4.2, we show that the first shock generates a negative comovement between interest rates and aggregate stock returns while the second shock generates a positive comovement. For this reason, we refer to the first shock as a pure monetary shock and the second shock as a central bank information shock.

Pure monetary shocks. A pure monetary shock ("MP shock") has form

$$\varepsilon^m(t) = \Delta_m e^{-\psi_m t}, \quad t \geq 0, \tag{18}$$

[4]If $z_{ss} \neq 0$, β_i would instead capture firm productivity with a more productive firm having a larger β_i (in the case where $z_{ss} > 0$).

where Δ_m and ψ_m parameterize the size of the initial shock at $t = 0$ and the speed of the subsequent reversal, respectively. Note that equation (18) is the typical functional form for MP shocks considered in the literature (see, e.g., Kaplan et al. 2018, Section IV).

CBI shocks. To motivate CBI shocks, let us first consider a total factor productivity (TFP) shock $\varepsilon^{TFP}(t)$ which we model as follows. Suppose that productivity is initially at its steady state value z_{ss}. A TFP shock impacts productivity immediately according to $z(t) = z_{ss} + \varepsilon^{TFP}(t)$ where

$$\varepsilon^{TFP}(t) = \Delta_{TFP} e^{-\psi_{TFP} t}, \quad t \geq 0. \tag{19}$$

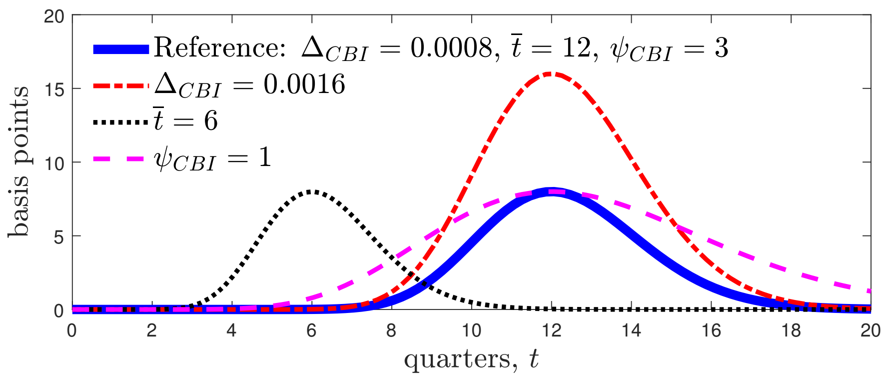
Here, Δ_{TFP} parameterizes the immediate impact of the TFP shock and ψ_{TFP} captures the speed of the subsequent reversal.

Similar to TFP shocks, a CBI shock $\varepsilon^{CBI}(t)$ also affects productivity according to $z(t) = z_{ss} + \varepsilon^{CBI}(t)$. Unlike TFP shocks, however, CBI shocks do not immediately impact productivity. Specifically, we parameterize CBI shocks as follows:

$$\varepsilon^{CBI}(t) = \Delta_{CBI} \times \left(t/\bar{t}\right)^{\psi_{CBI}\bar{t}} e^{-\psi_{CBI}(t-\bar{t})} \tag{20}$$

where Δ_{CBI}, $\psi_{CBI} > 0$, and $\bar{t} > 0$ are parameters. The functional form (20) implies a hump-shaped deviation in productivity—$\varepsilon^z(t)$ always starts off at zero at $t = 0$ and increases to reach its peak value of Δ_{CBI} at $t = \bar{t}$ before subsequently decaying to zero with ψ_{CBI} capturing the speed of the decay. The parameterization (20) therefore captures the idea that CBI shocks reveal information regarding the future prospects of the economy. In Figure 2, we illustrate the dependance of the CBI shock (20) on its parameters.

Figure 2: Illustration of central bank information shocks. This figure illustrates the central bank information (CBI) shock (20) for various parameter values. For reference, the solid line plots a CBI shock with parameter values $\Delta_{CBI} = 0.0008$, $\psi_{CBI} = 3$, and $\bar{t} = 12$. The other lines illustrate the effect of a change in the value of a single parameter (with all other parameters remaining unchanged from the reference values).



Aggregate stock market. We define the aggregate stock market as a claim on aggregate dividends $\Pi(t)$ which equals

$$\Pi(t) = \int_0^1 \left(\Phi_{it} - \iota_{it} - \frac{\kappa}{2}\iota_{it}^2\right) K_{it}\, di + \int_0^1 \Pi_j(t)\, dj$$

in real terms. The $\int_0^1 \left(\Phi_{it} - \iota_{it} - \frac{\kappa}{2}\iota_{it}^2\right) K_{it}\, di$ and $\int_0^1 \Pi_j(t)\, dj$ terms correspond to dividends from wholesalers and retailers, respectively; the final good producer pays out zero dividends in equilibrium. Note that equilibrium market clearing implies $\Pi(t) = C(t) - N(t)w(t)$.

The real value of aggregate stock market at time t, $S(t)$, equals the present value of future dividends

$$S(t) = \int_t^\infty e^{-\int_t^s r(u)du}\Pi(u)\, ds. \tag{21}$$

The corresponding nominal value is $S(t)/P(t)$. Assuming the economy is initially in steady state at $t = 0$, the return of the aggregate stock market upon impact of a shock at $t = 0$ is

$$r_{mkt} = \frac{S(t = 0^+) - S_{ss}}{S_{ss}} \tag{22}$$

where $S(t = 0^+)$ is the value of the stock market immediately after the arrival of the shock.

CAPM beta. We now define model-implied CAPM betas to connect our model to our empirical results.

Suppose the economy is initially in steady state at $t = 0$ so that wholesaler i's value equals $v_{ss}K_i(0)$ where v_{ss} denotes the steady state value to capital ratio. The return of wholesaler i upon impact of a shock at $t = 0$ is

$$r_i = \frac{v(t = 0^+; \beta_i)K_i(i) - v_{ss}K_i(0)}{v_{ss}K_i(0)} = \frac{v(t = 0^+; \beta_i) - v_{ss}}{v_{ss}} \tag{23}$$

where $v(t = 0^+; \beta_i)$ is the value to capital ratio immediately after the arrival of the shock.

The CAPM beta of wholesaler i is the elasticity of the wholesaler's firm value with respect the value of the aggregate stock market:

$$\beta_{CAPM,i} \equiv \frac{r_i}{r_{mkt}} \tag{24}$$

where r_{mkt} and r_i are given by equations (22) and (23), respectively. Note that the CAPM beta (24) is defined with respect to a given shock. In our quantitative exercises in Section 4, we take the shock to be a TFP shock (19) when computing CAPM betas.

4 Quantitative Analysis

4.1 Calibration

We compute perfect foresight transition path following unexpected shocks with the economy starting from its steady state. We do so using the numerical procedure described in Appendix C.2. We take a unit of time to be a quarter and simulate the model using the parameter values in Table 6.

We choose household preferences as follows. We set the household's subjective discount

Table 6: Parameters. The model uses the parameters in this table. Each time period in the model corresponds to a quarter.

Parameter		Value	Parameter		Value
Subjective discount rate	ρ	1.58/4%	Exit rate, wholesalers	χ	5.5/4%
Intertemporal elas. of subs.	$1/\gamma$	1	Initial capital endowment	K_{init}	1
Disutility of labor	φ	2.395	Capital coeff., wholesalers	α	1/3
Price adj. cost, retailers	θ	100	Capital adj. cost, wholesalers	κ	15
Elas. of subs., final good	ϵ	10	Depreciation rate	δ	6.86/4%
Taylor rule coeff.	ϕ_π	1.25			
Cross-sectional distribution of productivity betas, Γ					
Bin		β_i	Bin		β_i
Bin #1		0.35	Bin #6		1.01
Bin #2		0.56	Bin #7		1.12
Bin #3		0.69	Bin #8		1.26
Bin #4		0.79	Bin #9		1.46
Bin #5		0.91	Bin #10		1.84
Shocks					
MP shock, size	Δ_m	0.0037	CBI, size at peak	Δ_{CBI}	0.0008
MP shock, mean reversion	ψ_m	0.5	CBI, time of peak	$\bar{t}$	12
TFP shock, size	Δ_{TFP}	0.01	CBI, speed of decline	ψ_{CBI}	3
TFP shock, mean reversion	ψ_{TFP}	$-\log 0.9$			

rate to $\rho = 1.58/4\%$ so that the annualized real rate of interest is 1.58% in steady state. This value corresponds to the average of the Cleveland Fed's estimate of the one year real interest rate over the period 1982-2019 (see the series REAINTRATREARAT1YE from FRED). We set the intertemporal elasticity of substitution $1/\gamma$ to one which is the same value used in Kaplan et al. (2018), henceforth KMV, and Ottonello and Winberry (2020), henceforth OW. We set the disutility of labor $\varphi = 2.395$ in order to target steady state hours of $N_{ss} = 1/3$.

We set the elasticity of substitution across intermediate goods to $\epsilon = 10$ as in KMV and OW; this implies a steady state markup of 11%. We set retailers' price adjustment cost parameter to 100 which implies a slope of $\epsilon/\theta = 0.1$ in the New Keynesian Phillips curve (13); the latter is the slope value in KMV and OW. We set the coefficient on inflation to

$\phi_\pi = 1.25$ in the Taylor rule (16) exactly as in KMV and OW.

We choose wholesalers' parameters as follows. We set the exit rate to $\chi = 5.5/4\%$ based on an average plant exit rate of 5.5% per anum documented in Lee and Mukoyama (2015, Table 2). We normalize the initial capital endowment to one, $K_{init} = 1$. We set the capital coefficient to $\alpha = 1/3$ in the production function which implies a steady state labor share of $(1-\alpha)(\epsilon-1)/\epsilon = 60\%$. We set capital adjustment costs to $\kappa = 15$ so that the impulse response of aggregate investment to a pure monetary shock is roughly twice that of the response in aggregate output (see the estimates in, e.g., Christiano et al. 2005, Fig. 1). We choose the capital depreciation rate to target a steady state capital growth rate $d \log k/dt = (\iota_{ss} - \delta)$ of 5% per anum based on the average cross-sectional capital growth rate in our sample (see Table 1). This results in setting $\delta = 6.86/4\%$.

We calibrate the cross-sectional distribution of productivity betas Γ to target the distribution of CAPM betas in the data. Specifically, we take Γ to be a histogram of ten equally-sized bins in which the value of beta β_i is the same within each bin. We then choose the ten bin values $\{\beta_i\}_{i=1,\ldots,10}$ to minimize the sum squared error $\sum_{i=1}^{10} \left(\beta_{CAPM,i} - \beta_{CAPM,i}^{data}\right)^2$ between the model-implied CAPM betas $\beta_{CAPM,i}$ and their data counterparts $\beta_{CAPM,i}^{data}$ subject to the constraint that the cross-sectional average of betas equal one. In computing the model-implied CAPM beta (24), we take the shock to be a TFP shock (19) with initial size $\Delta_{TFP} = 0.01$ and rate of decay $\psi_{FTP} = -\log 0.9$ (the implied quarterly autocorrelation coefficient is 0.9, a typical value considered by the real business cycle; see, e.g., King et al. 1988). We take the data counterparts $\beta_{CAPM,i}^{data}$ to be the median value of CAPM betas within each decile; these values equal 0.33, 0.57, 0.72, 0.84, 0.97, 1.09, 1.22, 1.38, 1.61, and 2.05 for deciles one through ten, respectively. The solution to the minimization problem gives productivity betas of 0.35, 0.56, 0.69, 0.79, 0.91, 1.01, 1.12, 1.26, 1.46, and 1.84 in deciles one through ten, respectively.

Table 7: Model-implied moments.

Moment	Description	Value	Moment	Description	Value
		A. Steady state moments			
r_{ss}	Real rate, annualized	1.58%	N_{ss}	Hours	1/3
π_{ss}	Inflation, annualized	0%	$N_{ss}w_{ss}/Y_{ss}$	Labor share of output	60%
i_{ss}	Nominal rate, annualied	1.58%	C_{ss}/Y_{ss}	Consumption to output	75.2%
$1/p_w^\star - 1$	Markup	11%	I_{ss}/Y_{ss}	Investment to output	24.8%
$\iota_{ss} - \delta$	Capital growth, annualized	5%	Φ_{ss}	Profitability/ROA, annualized	17.5%
		B. CAPM betas			
$\beta_{CAPM,1}$	CAPM beta, decile 1	0.06	$\beta_{CAPM,6}$	CAPM beta, decile 1	0.82
$\beta_{CAPM,1}$	CAPM beta, decile 2	0.30	$\beta_{CAPM,7}$	CAPM beta, decile 1	0.95
$\beta_{CAPM,1}$	CAPM beta, decile 3	0.45	$\beta_{CAPM,8}$	CAPM beta, decile 1	1.11
$\beta_{CAPM,1}$	CAPM beta, decile 4	0.57	$\beta_{CAPM,9}$	CAPM beta, decile 1	1.34
$\beta_{CAPM,1}$	CAPM beta, decile 5	0.70	$\beta_{CAPM,10}$	CAPM beta, decile 1	1.78

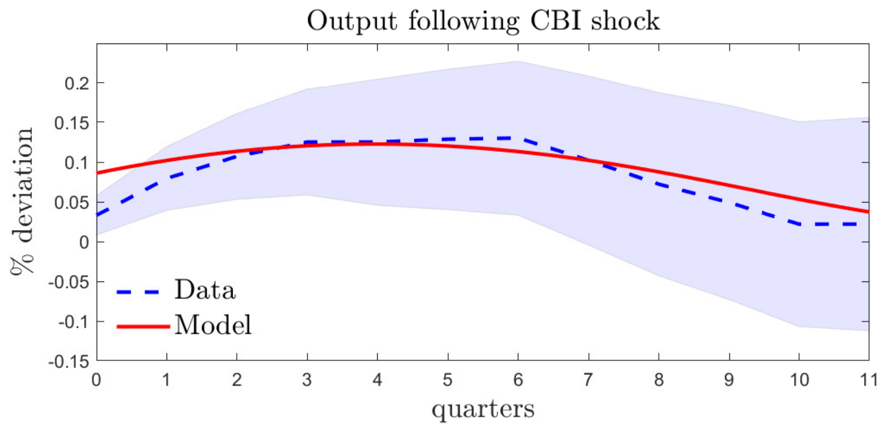
The corresponding model-implied CAPM betas are 0.06, 0.30, 0.45, 0.57, 0.70, 0.82, 0.95, 1.11, 1.34, and 1.78 for deciles one through ten, respectively.

Table 7 summarizes the model-implied moments; Figure B.1 in Appendix C.1 displays the steady state capital distribution.

Monetary shocks. We investigate transition paths following MP and CBI shocks. For the MP shock (18), we set the speed of mean-reversion to $\psi_m = 0.5$ as in KMV and OW and choose the initial size of the shock to be $\Delta_m = 0.0037$ so that the nominal interest rate increases by 25 basis points upon impact of the shock.

For the CBI shock (20), we choose parameters so that (1) the nominal interest rate increases by 25 basis points upon impact of the shock, and (2) the model-implied output path following the CBI shock is in line with the data. Satisfying requirement (1) means setting the peak of the CBI shock to $\Delta_{CBI} = 0.0008$. For requirement (2), we first estimate the output path following a CBI shock by estimating cumulative GDP growth following a CBI shock,

Figure 3: Calibration of CBI shock. The dashed line plots the point estimates of cumulative output growth following a 25 basis point CBI shock; the shaded region plots the plus and minus two standard error confidence bands. The solid line plots the model-implied counterpart for output growth.

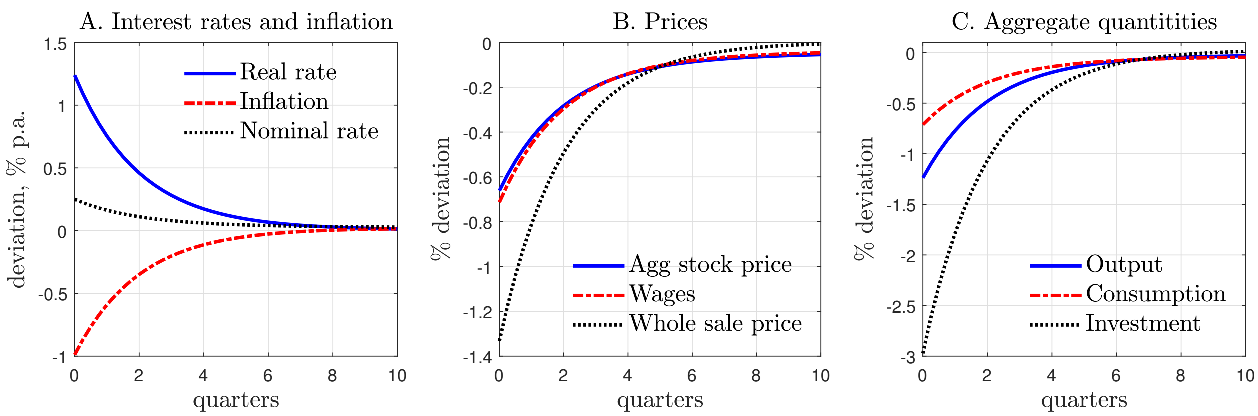


$\log GDP_{t+h} - \log GDP_{t-1} = a_h + b_h CBI_t + \epsilon_{t+h}$, over the period 1990Q1-2019Q2 for which CBI shocks are available. The resulting point estimates for the transition path following a 25 basis point CBI shock is $0.0025 \times \widehat{b}_h$ where $\widehat{b}_h$ is the slope coefficients estimate for quarter h. The dashed line in Figure 3 plots these point estimates while the shaded region plots the corresponding two standard error confidence band. We then choose the remaining parameters of the CBI shock (20), ψ_{CBI} and $\bar{t}$, so that the model-implied output path following a CBI shock is in line with the data. This procedure results in setting $\bar{t} = 12$ and $\psi_{CBI} = 3$. The solid line in Figure 3 shows that the resulting model-implied path for output is indeed in line with the data.

4.2 Transition paths following MP and CBI shocks

The main finding of this section is that shocks to the future path of productivity $\varepsilon^{CBI}(t)$ are consistent with the effects of CBI shocks observed in the data—both in the time-series and in the cross-section.

Figure 4: Aggregate responses to a contractionary MP shock. This figure plots the aggregate impulse response to a pure monetary shock (18) with $\Delta_m = 0.0037$ and $\psi_m = 0.5$. The transition path is the perfect foresight path following an unexpected shock with the economy starting from its steady state.



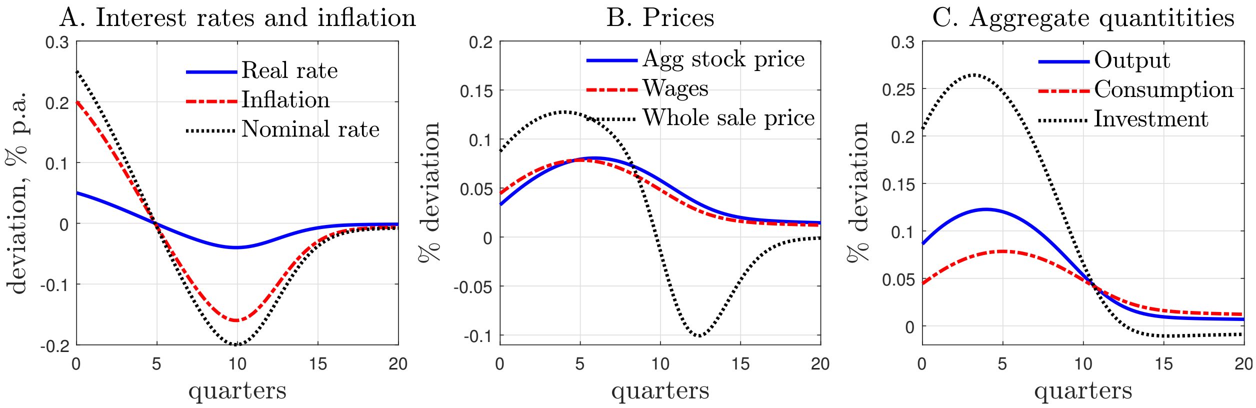
4.2.1 Aggregate response

MP shock. Figure 4 shows the aggregate response following the calibrated contractionary MP shock. We see that the MP shock decreases economic activity and generates a negative comovement between interest rates and stock returns—the nominal rate increases by 25 basis points while the aggregate stock price decreases by 66 basis points upon impact of the shock.

The reason for the decrease in economic activity is as follows. A contractionary MP shock increases nominal rates, and since prices are sticky, also increases the real rate. Higher real rates dampen investment by decreasing the present value of the cash flows generated by capital. Higher real rates also decrease household demand for consumption due to intertemporal smoothing. The resulting contraction in economic activity lowers inflation and is reflected in a drop in the value of the aggregate stock market.

Note that for the case of a MP shock, our HANK setting reduces to that of a representative agent New Keynesian (RANK) model in which firm heterogeneity is longer present (i.e., $\beta_i = \beta$ for all i). To see this, note that $z(t) = z_{ss} = 0$ for a MP shock so that wholesalers'

Figure 5: Aggregate responses to an expansionary CBI shock. This figure plots the aggregate impulse response to a CBI shock (20) with $\Delta_{CBI} = 0.0008$, $\psi_{CBI} = 3$, and $\bar{t} = 12$. The transition path is the perfect foresight path following an unexpected shock with the economy starting from its steady state.



profitability (6) and investment rate (9) no longer depend on β.

CBI shock. Figure 5 shows the aggregate response following the calibrated CBI shock. We see that there is a positive comovement between interest rates and aggregate stock returns—upon impact, the 25 basis point increase in the nominal rate is accompanied by a 3 basis point increase in the aggregate stock price (which subsequently reaches a peak of 8 basis points above its steady state value).

The reason for the positive comovement is as follows. First, the CBI shock carries positive news regarding future productivity. This results in a boom in economic activity which is reflected by an increase in the aggregate stock price. Second, the CBI shock induces a hump-shaped consumption response with consumption peaking around $t = 5$ quarters after the shock (see the dash-dot line in panel C of Figure 5). This hump-shaped response—which is also present for output, investment, and hours—is due to firms' motives to gradually build up capital following a CBI shock (quickly building up capital is suboptimal since there is no immediate increase in productivity following a CBI shock). Next, households' incentives to smooth the increase in consumption prior to $t = 5$ decrease their demand for bonds which drives up the real rate (see panel A). Together with the increase in inflation, nominal rates also go up. This is what generates the positive comovement between interest rates and stock returns following a CBI shock.

News regarding future productivity is key for generating a positive comovement between interest rates and stock returns. For example, the TFP shock (19) that immediately affect productivity is unable to generate a positive comovement between interest rates and stock returns. We demonstrate this result in Appendix D.

4.2.2 Cross-sectional response

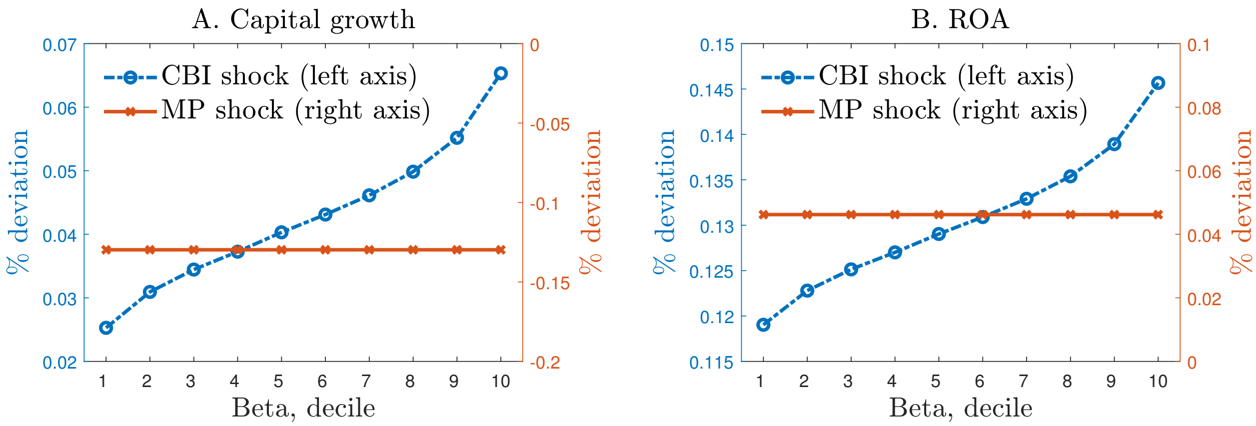
In this section, we show that the cross-sectional response to MP and CBI shocks in our model are both consistent with our empirical findings.

We begin by reporting our model's implications for cross-sectional differences in firms' growth in capital following a shock. Consider a firm whose beta is in the ith decile. Its cumulative growth rate in capital h quarters after a shock at $t = 0$ equals $\log K_i(h) - \log K_i(0) = \int_0^h [\iota(t; \beta_i) - \delta]\, dt$ compared to $\int_0^h [\iota_{ss} - \delta]\, dt$ had no shock occurred at $t = 0$. The effect of the shock on capital accumulation is therefore $\int_0^h [\iota(t; \beta_i) - \iota_{ss}]\, dt$.

Panel A of Figure 6 plots the effect of CBI and MP shocks on capital accumulation for a horizon of $h = 8$ quarters. We see that capital growth is higher for firms with higher betas following a CBI shock (see the line with the circles) while there is no cross-sectional difference following a MP shock (see the line with the crosses). These results are consistent with our empirical findings in Section 2.2.

Panel B of Figure 6 reports the results for the growth in profitability (6) $h = 8$ quarters following a shock: $\log \Phi(t; \beta_i) - \log \Phi_{ss}$. Similar to the results for capital growth, we see

Figure 6: Cross-sectional response: $h = 8$ quarters. Panels A and B plot cumulative growth in capital and ROA $h = 8$ quarters following a shock, respectively. The lines with the crosses and circles report results for pure monetary and CBI shocks, respectively.



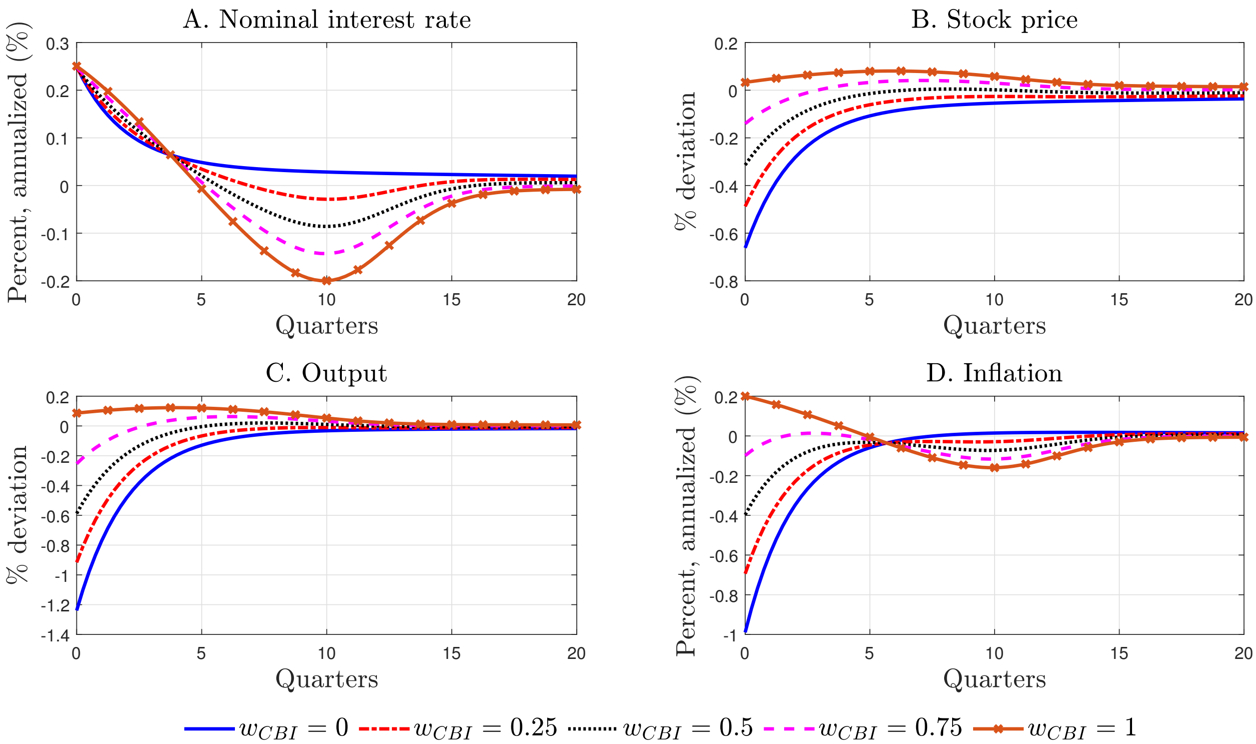
that there is a positive cross-sectional difference following a CBI shock and zero difference following a pure monetary shock. These results are consistent with our empirical findings in Section 2.4.

4.3 Fed information effect and inflation

While we have analyzed pure monetary and CBI shocks in Section 4.2, interest rate shocks are, more generally, combinations of pure monetary and CBI shocks. In this section, we analyze the impact of mixtures of pure monetary and CBI shocks. We show that the presence of information in a given interest rate shock can dampen the response of inflation. That is, the presence of the Fed information effects implies that policy makers must respond more strongly to inflation that would be otherwise necessary. This is consistent with concerns recently raised by policy makers.[5]

[5] For example, Fed Governor Christopher J. Wallace stated at the European Economics and Financial Center, London, United Kingdom on October 18, 2023: "[b]ut I also can't avoid thinking about the second scenario, where demand and economic activity continue at their recent pace, possibly putting persistent upward pressure on inflation and stalling or even reversing progress toward 2 percent... Thus, more action would be needed on the policy rate to ensure that inflation moves back to target and expectations remain

Figure 7: Fed information effect and inflation. Describe... The transition path is the perfect foresight path following an unexpected shock with the economy starting from its steady state.



We define a mixed interest rate shock as follows. Consider the calibrated MP and CBI shocks, $\varepsilon^m(t)$ and $\varepsilon^{CBI}(t)$, respectively. An economy hit by a mixed interest rate shock simultaneously encounters a CBI shock of size $w_{CBI} \times \varepsilon^{CBI}(t)$ and a MP shock of size $(1 - w_{CBI}) \times \varepsilon^m(t)$. Here, the weight $w_{CBI} \in [0, 1]$ parameterizes the strength of the information effect in the mixed interest rate shock.

Figure 7 shows the impulse responses following mixed interest rate shocks as we vary w_{CBI}. Although all values of w_{CBI} result in an initial interest rate spike of 25 basis points (see panel A), the inflation response is very different (see panel D). For example, when $w_{CBI} = 0.75$ so that the information effect is strong, we see that inflation remains almost unchanged (see the

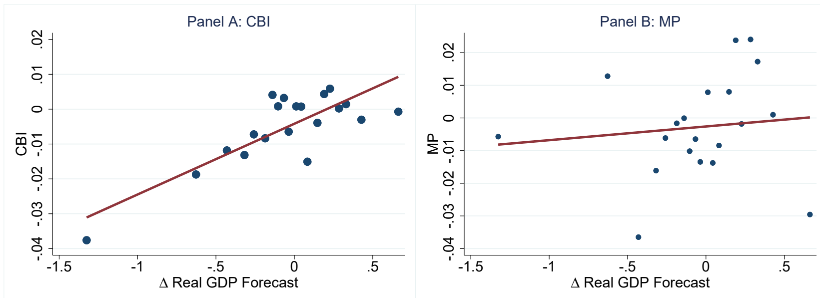
anchored." Also see Section 1 for a related quote by Fed Chair Jerome H. Powell.

dashed line in panel D). In contrast, inflation decreases significantly when the information effect is weak. The reason for the sluggish inflation response when the information effect is strong can be seen panel C. Specifically, output responds strongly when the information effect is strong. This increase in economic activity increases inflation and offsets the dampening effect of higher interest rates on inflation. Finally, panel B shows that the strength of the information effect can be gleamed from the stock price response with stock prices responding more positively when the information effect is stronger.

5 Conclusion

Over the past three decades, press releases and announcements have accompanied the Federal Reserves' announcement of their short-term nominal interest rate. We study firm-level investment rate patterns and revisions in analysts forecasts to provide evidence that FOMC announcements change expectations of firm profitability, which, in turn, affects firm investment. This channel, which we call the "profitability channel", has a heterogeneous impact in the cross-section of firms. Specifically, we show that revisions in analyst forecasts of firm profitability and firm investment rates are more sensitive to the component of a monetary policy shock that the existing literature has identified as a Central Bank information shock.

Figure A.1: Tealbook revisions in real GDP forecasts and monetary policy shocks. Panels A and B show the binned scatter plot of revisions in Tealbook forecasts of real GDP growth over the three quarters following a FOMC meeting against the corresponding CBI and MP shocks, respectively. Both the CBI and MP shocks are standardized.



Appendix

A Fed forecast revisions and the CBI shock

Jarociński and Karadi (2020) provide examples of CBI shock realizations being associated with mentions of changes in the Fed's economic outlook in FOMC announcements. In addition, that paper provides evidence based on structural vector autoregressions that CBI shocks are associated with realized changes in future economic and financial conditions. In this section, we use Tealbook (formerly Greenbook) data from the Philadelphia Fed to provide further corroborating evidence that the CBI shock is associated with revisions in the Fed's private forecast of future economic conditions. The Tealbook contains the Fed's future economic projections prior to each FOMC meeting.

In Figure A.1, we plot CBI and MP shock realizations against revisions in the Fed's forecast of real GDP growth. The latter is computed as the change in the real GDP growth forecast from the previous FOMC meeting to the current meeting. Following Nakamura and Steinsson (2018), we focus on the forecast for the next three quarters, and compute the average of the revisions for each of those three quarters.

Panel A of Figure A.1 shows that there is a positive correlation between the CBI shock and the revision in the real GDP growth forecast. This suggests that even though Tealbook forecasts are not publicly available in real-time (Tealbooks are made available to the public with a five year lag), the Fed's assessment of future economic outlooks is at least partially communicated to the private sector during FOMC announcements, and the CBI shock captures some of the information shock. In contrast, panel B shows that there is almost no correlation between the Tealbook revisions in real GDP forecasts and the MP shock.

B Derivations

B.1 Wholesalers' value function

Apply the Feynman-Kac formula to write equation (7) in recursive form, as follows:

$$\begin{aligned} r(t)V(t,K;\beta) = \max_{\iota} \ & \Phi(z(t),p_w(t),w(t);\beta)K(t) - \left(\iota + \frac{\kappa}{2}\iota^2\right)K \\ & + V_t(t,K;\beta) + (\iota-\delta)KV_K(t,K;\beta) - \chi V(t,K;\beta), \end{aligned} \tag{A.1}$$

where V_x denotes the partial derivative of V with respect to $x \in \{t, K\}$. Next, substitute $V(t,K;\beta) = Kv(t;\beta)$ into equation (A.1) to obtain equation (8) .

B.2 New Keynesian Phillips curve

To derive the New Keynesian Phillips curve (13), write the retailer's problem (12) recursively:

$$r(t)\widetilde{V}(t,p) = \max_{\pi} \left[\frac{p}{P(t)} - p_w(t)\right] Y(t) \left(\frac{p}{P(t)}\right)^{-\epsilon} - \frac{\theta}{2}\pi^2 Y(t) + \widetilde{V}_t(t,p) + \pi p \widetilde{V}_p(t,p) \tag{A.2}$$

where $\widetilde{V}$ denotes retailers' value function. The first order condition is

$$\theta\pi(t,p)Y(t) = p\widetilde{V}_p(t,p). \tag{A.3}$$

The envelope condition gives

$$r(t)\widetilde{V}_p(t,p) = \left[1 - \epsilon + \epsilon\frac{p_w(t)P(t)}{p}\right] \frac{Y(t)}{P(t)} \left(\frac{p}{P(t)}\right)^{-\epsilon} + \widetilde{V}_{tp}(t,p) + \pi(t,p)\widetilde{V}_p(t,p) + p\pi(t,p)\widetilde{V}_{pp}(t,p) \tag{A.4}$$

Let $\pi(t) = \pi(t, \pi(t))$ denote inflation along the optimal price path $p(t)$. Then, differentiating equation (A.3) with respect to time along the optimal price path gives

$$\theta\pi'(t)Y(t) + \theta\pi(t)Y'(t) = p'(t)\widetilde{V}_p(t,p(t)) + p(t)\left[\widetilde{V}_{tp}(t,p(t)) + p'(t)\widetilde{V}_{pp}(t,p(t))\right]. \tag{A.5}$$

Substituting equations (A.3) and (A.4) into equation (A.5) gives

$$\theta\pi'(t)Y(t) + \theta\pi(t)Y'(t) = \theta r(t)\pi(t)Y(t) - p(t)\left[1 - \epsilon + \epsilon\frac{p_w(t)P(t)}{p(t)}\right] \frac{Y(t)}{P(t)} \left(\frac{p(t)}{P(t)}\right)^{-\epsilon}. \tag{A.6}$$

In a symmetric equilibrium, we have $p(t) = P(t)$. Substituting this condition into equation (A.6) leads to the New Keynesian Phillips curve (13).

B.3 Household's problem

The household's problem in recursive form is

$$\rho U(t,B) = \max_{C,N} \frac{C^{1-\gamma}}{1-\gamma} - \varphi N + U_t(t,B) + [r(t)B - C + w(t)N + \Pi(t)]\, U_B(t,B), \tag{A.7}$$

where $U(t,B)$ denotes the household's value function. The first order conditions for C and N are

$$C(t,B)^{-\gamma} = U_B(t,B), \tag{A.8}$$

$$\text{and} \quad \varphi = w(t)U_B(t,B), \tag{A.9}$$

respectively. Combining equations (A.8) and (A.9) gives the labor supply condition (14).

To derive the consumption Euler equation (15), note that the envelope condition for the household's problem (A.7) is

$$\rho U_B(t,B) = U_{tB}(t,B) + r(t)U_B(t,B) + [r(t)B - C + w(t)N + \Pi(t)]\, U_{BB}(t,B). \tag{A.10}$$

Next, differentiating the first order condition (A.8) with respect to t along the optimal path $C(t) = C(t, B(t))$ gives

$$-\gamma C(t)^{-\gamma-1}C'(t) = U_{tB}(t,B(t)) + B'(t)U_{BB}(t,B(t)). \tag{A.11}$$

The consumption Euler equation (15) follows from combining equations (A.10) and (A.11).

C Numerical solution

C.1 Computing the steady state

The stationary version of the wholesalers' problem (8) is

$$r_{ss}v_{ss} = \max_{\iota} \Phi(z_{ss}, p_w^\star, w_{ss}) - \iota - \frac{\kappa}{2}\iota^2 + (\iota - \delta)v_{ss} - \chi v_{ss}. \tag{B.1}$$

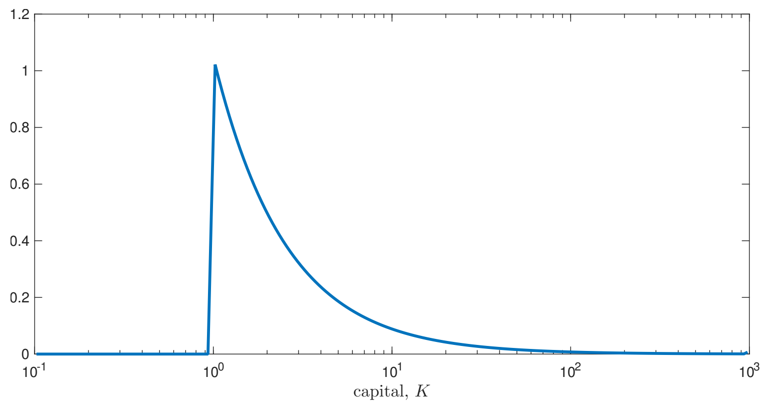
Note that the normalization for steady state productivity $z_{ss} \equiv 0$ implies that profitability (6) is independent of β in steady state. As a result, the steady state value function v_{ss} is also independent of β. Plugging in the first order condition for steady state investment $1 + \kappa\iota_{ss} = v_{ss}$ into equation (B.1) characterizes ι_{ss} as the solution to a quadratic equation:[6]

$$\iota_{ss} = r_{ss} + \delta + \chi - \sqrt{(r_{ss}+\delta+\chi)^2 + \frac{2}{\kappa}\left[r_{ss} + \delta + \chi - \Phi(z_{ss}, p_w^\star, w_{ss})\right]}. \tag{B.2}$$

The steady state distribution of capital $f_{ss}(K)$ solves the stationary version of the Kolmorogov

[6]The other root of the quadratic equation is not the correct solution as it implies an infinite value function.

Figure B.1: Steady state cross-sectional distribution of capital.



forward equation (KFE) (10),

$$0 = -\frac{\partial}{\partial K}\left[\left(\iota_{ss} - \delta\right) K f_{ss}(K)\right] + \chi\left[\delta(K; K_{init}) - f_{ss}(K)\right]. \tag{B.3}$$

As is the case with the value function v_{ss}, the stationary distribution is also independent of β. We solve equation (B.3) numerically using the algorithm described in Appendix C.2 (see equation (B.10)). Figure B.1 plots the solution for the baseline parameters listed in Table 6.

Steady state wages w_{ss} solve the steady state version of the labor supply condition (14),

$$w_{ss} C_{ss}(w_{ss})^{-\gamma} = \varphi, \tag{B.4}$$

where $C_{ss}(w_{ss})$ is the aggregate consumption implied by firm policies when wages equal w_{ss}:

$$C_{ss}(w_{ss}) = Y_{ss}(w_{ss}) - I_{ss}(w_{ss}). \tag{B.5}$$

Here, $Y_{ss}(w_{ss}) = \int n(z_{ss}, p_w^\star, w_{ss})^{1-\alpha} K f_{ss}(K; w_{ss})\, dK$ and $I_{ss}(w_{ss}) = \int \left[\iota_{ss}(w_{ss}) + \frac{\kappa}{2}\iota_{ss}(w_{ss})^2\right] K f_{ss}(K; w_{ss})\, dK$ are the steady state aggregate output and aggregate investment when wages equal w_{ss}, respectively.

C.2 Computing the transition path

There are two steps. First, we solve for policies and aggregate outcomes under arbitrary price paths. Second, we use equilibrium conditions to solve for equilibrium price paths.

Step 1: outcomes given price paths. We solve the associated problems using upwind finite difference schemes (see, e.g., https://benjaminmoll.com/codes/ for examples).

Let $\mathcal{P} = \{z^n, (\varepsilon^m)^n, p_w^n, w^n, r^n : n = 0, 1, ..., \overline{N}\}$ be a given discretized path of shocks and prices where x^n denotes $x(n\Delta)$, Δ is the time step, and $\overline{N}$ is the maximum number of time steps to consider. In our numerical implementation, we set $\Delta = 0.25$ quarters and set $\overline{N}$ to be large enough such that the economy is sufficiently close to steady state when $n = \overline{N}$.

The discretized version of the wholesalers' problem (8) is

$$r^n v^n(\beta) = \max_{\iota} \Phi(z^n, p_w^n, w^n; \beta) - \iota - \frac{\kappa}{2}\iota^2 + \frac{v^{n+1}(\beta) - v^n(\beta)}{\Delta} + (\iota - \delta)v^n(\beta) - \chi v^n(\beta). \quad \text{(B.6)}$$

The solution to equation (B.6) gives the update scheme

$$v^n(\beta) = \frac{\Phi(z^n, p_w^n, w^n; \beta) + \frac{\kappa}{2}\iota^n(\beta)^2 + v^{n+1}(\beta)/\Delta}{r^n + \delta + \chi + 1/\Delta}, \quad v^{\overline{N}}(\beta) = v_{ss}, \quad \text{(B.7)}$$

with $\iota^n(\beta) = \kappa^{-1}[v^n(\beta) - 1]$. In implementing the scheme (B.7), we noticed that arbitrary off-equilibrium price paths $\mathcal{P}$ can generate extremely large values for $\iota^n(\beta)$ which makes it difficult to achieve convergence in the second step below. For this reason, we restrict $\iota^n(\beta)$ to the interval $[\iota_{min}, \iota_{max}]$ where ι_{min} and ι_{max} are numerical parameters. After convergence in step 2, we verify that the numerical bound $[\iota_{min}, \iota_{max}]$ never binds along the actual equilibrium price path.

After computing the policy $\iota^n(\beta)$, we solve the nonstationary KFE (10) to obtain the path for the capital distribution in order to compute aggregate outcomes. The discretized nonstationary KFE is

$$\frac{f^{n+1}(k_j; \beta) - f^n(k_j; \beta)}{\Delta} = [\mathscr{L}^n(\beta)]^{\dagger} f^{n+1}(k_j; \beta), \quad \text{(B.8)}$$

where we work with an evenly-spaced grid $\{k_j : j = 1, ..., J\}$ for log capital $k = \log K$, and $[\mathscr{L}^n(\beta)]^{\dagger}$ denotes the adjoint of the infinitesimal generator $\mathscr{L}^n(\beta)$ for log capital, which equals $[\mathscr{L}^n(\beta)]f(k) = [\iota^n(\beta) - \delta]f'(k) + \chi[f(k_{init}) - f(k)]$ where $k_{init} = \log K_{init}$.

Equation (B.8) leads to the following implicit scheme:

$$\mathbf{f}^{n+1}(\beta) = \left\{\mathbf{I} - \Delta[\mathbf{L}^n(\beta)]^T\right\}^{-1} \mathbf{f}^n(\beta), \quad \mathbf{f}^0(\beta) = \mathbf{f}_{ss}. \quad \text{(B.9)}$$

Here, $\mathbf{f}^n(\beta)$ denotes $f^n(k_j; \beta)$ stacked as column vector and $\mathbf{I}$ is the $J \times J$ identity matrix. The matrix $\mathbf{L}^n(\beta)$ is an upwinded finite difference approximation of $\mathscr{L}^n(\beta)$ over the capital grid; its transpose $[\mathbf{L}^n(\beta)]^T$ is then an approximation of $[\mathscr{L}^n(\beta)]^{\dagger}$. In solving equation (B.9), we take the grid for log capital to be an evenly spaced grid with $J = 201$ points between $k_1 = \log 0.1$ and $k_J = \log 1000$. For numerical purposes, we also impose reflecting boundary conditions at k_1 and k_J; such boundary conditions are innocuous so long as we choose the capital grid to be sufficiently wide.

The steady state distribution, which appears as the initial condition in the scheme (B.9), can be computed as

$$\mathbf{f}_{ss} = \frac{\widetilde{\mathbf{f}}_{ss}}{\mathbf{1}^T\widetilde{\mathbf{f}}_{ss}}, \quad \widetilde{\mathbf{f}}_{ss} = \left[\left(\widetilde{\mathbf{L}^{ss}}\right)^T\right]^{-1} \mathbf{e}_{\underline{j}}. \quad \text{(B.10)}$$

Here, $\mathbf{1}$ denotes a $J \times 1$ column vector of ones. The matrix $\widetilde{\mathbf{L}^{ss}}$ modifies the matrix $\mathbf{L}^{ss}$, a upwinded finite difference approximation to $\mathscr{L}^n$ with ι^n set to ι_{ss}, as follows. Let $\underline{j}$ be any index for which the steady state log capital distribution takes positive mass (e.g., setting $\underline{j} = \min\{j \in \{1, ..., J\}$:

$k_j \geq k_{init}\}$ suffices). Then, the rows of $\left(\widetilde{\mathbf{L}^{ss}}\right)^T$ are identical to that of $\left(\mathbf{L}^{ss}\right)^T$ for all rows $j \neq \underline{j}$. Row $\underline{j}$ is, however, modified to be $\mathbf{e}_{\underline{j}}^T$ where $\mathbf{e}_{\underline{j}}$ denotes a $J \times 1$ column vector whose entries are all zero except for a value of one at entry $\underline{j}$.

After computing $\iota^n(\beta)$ and $f^n(k, \beta)$, we compute aggregate investment I^n and aggregate output Y^n. During this step, we use a trapezoidal quadrature rule when evaluating the integrals over capital. We also compute the inflation implied by the path $\mathcal{P}$ through the Taylor rule (16) and the Fisher equation (17): $\pi^n = (r^n - \rho - \varepsilon^{m,n}) / (\phi_\pi - 1)$. Finally, with I^n, Y^n, and π^n in hand, we compute the implied aggregate consumption through the equilibrium good market clearing condition $C^n = Y^n \left(1 - \frac{1}{2}\theta\pi^n\right) - I^n$.

Step 2: equilibrium price paths. In the second step, we compute the equilibrium price path as the solution to the following root finding problem $\mathbf{F}(\mathbf{x}) = \mathbf{0}$ where $\mathbf{x} = [(r^n)_{n\in\mathcal{N}} \; (\log w^n)_{n\in\mathcal{N}} \; (\log p_w^n)_{n\in\mathcal{N}}]'$ stacks the price paths along all time nodes $n \in \mathcal{N} = \{0, 1, ..., \overline{N}\}$, and

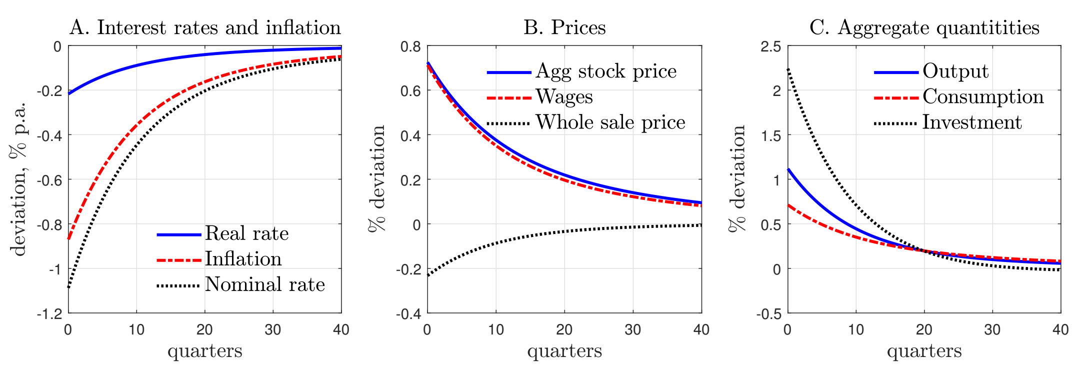
$$\mathbf{F}(\mathbf{x}) = \begin{bmatrix} \left(\varphi(C^n)^{-\gamma} - w^n\right)_{n\in\mathcal{N}} \\ \left(r^n - \rho - \gamma\frac{\log C^{n+1} - \log C^n}{\Delta}\right)_{n\in\mathcal{N}} \\ \left(\frac{\pi^{n+1} - \pi^n}{\Delta} + \frac{\epsilon}{\theta}\left(p_w^n - p_w^\star\right) - \left(r^n - \frac{\log Y^{n+1} - \log Y^n}{\Delta}\right)\pi^n\right)_{n\in\mathcal{N}} \end{bmatrix} \tag{B.11}$$

stacks the equilibrium condition for labor market clearing (14), the consumption Euler equation (15), and the New Keynesian Phillips curve (13) along the entire transition path. Note that given $\mathbf{x}$, $\mathbf{F}(\mathbf{x})$ is computed following the procedure outlined in step 1 above. We solve the root finding problem using Broyden's method.

D Results for TFP shocks

Figure C.1 reports the impulse response following an expansionary TFP shock (C.1) with size $\Delta_{TFP} = 0.01$ and speed of mean reversion $\psi_{TFP} = -\log 0.9$. We see that the TFP shock generates a negative comovement between interest rates (see panel A) and stock prices (see panel B).

Figure C.1: Aggregate responses to an expansionary TFP shock.



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