Monetary Policy and Innovation*

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Abstract

We document that monetary policy has a substantial impact on innovation activities. After a tightening shock of 100 basis points, research and development (R&D) spending declines by about 1 to 3 percent and venture capital (VC) investment declines by about 25 percent in the following 1 to 3 years. Patenting in important technologies, as well as a patent-based aggregate innovation index, declines by up to 9 percent in the following 2 to 4 years. Based on previous estimates of the sensitivity of output to innovation activities, these magnitudes imply that output could be 1 percent lower after another 5 years. Monetary policy can influence innovation activities by changing aggregate demand and correspondingly the profitability of innovation, and by changing financial market conditions. Both channels appear relevant in the data. Our findings suggest that monetary policy may affect the productive capacity of the economy in the longer term, in addition to the well-recognized near-term effects on economic outcomes.

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I. Introduction

Since at least the influential American Economic Association presidential address by Milton Friedman in 1968 (Friedman, 1968), discussions about monetary policy have commonly focused on its short-run impact. The productive capacity of the economy in the longer term is often presumed to be separate from the conduct of monetary policy, which Blanchard (2018) refers to as the "independence hypothesis." A small and growing body of work has been interested in the possible longer-term consequences of monetary policy, which may operate through the influence of monetary policy on innovation and technological progress (Stadler, 1990; Moran and Queralto, 2018; Grimm, Laeven, and Popov, 2022; Amador, 2022; Fornaro and Wolf, 2023; Jordà, Singh, and Taylor, 2023; Ma, 2023). For example, following monetary policy contractions, reductions in aggregate demand can decrease the profitability and incentives for innovation. Tighter financial conditions and lower risk appetite can decrease funding for innovation. A slower pace of innovation may then have lasting effects.

To date, there have been limited empirical analyses about the impact of monetary policy on innovation. This sparsity of systematic evidence is somewhat surprising. Casual observations suggest that shifts in the interest environment over the past decade have had noticeable effects on innovation funding such as VC investment. During the years of low interest rates, venture funding was abundant and startups expanded rapidly. As interest rates increased substantially since early 2022, venture funding fell sharply and startups struggled to survive (National Venture Capital Association, 2023). In addition, there is accumulating evidence that innovation is affected by demand and financial conditions (King and Levine, 1993; Barlevy, 2007; Brown, Fazzari, and Petersen, 2009; Ouyang, 2011; Huber, 2018; Anzoategui et al., 2019; Duval, Hong, and Timmer, 2020; Queralto, 2020), and that both demand and financial conditions respond to monetary policy (Christiano, Eichenbaum, and Evans, 1999; Bernanke and Kuttner, 2005; Gertler and Karadi, 2015). It seems natural to piece together these separate lines of inquiry.

In this paper, we perform an extensive empirical investigation about the effects of monetary policy on innovation activities, using a variety of metrics of innovation. In addition to the aggregate investment in intellectual property products (including R&D) from the national accounts and the R&D spending of public companies, we utilize measures based on VC investment and patent filings. Venture capital is well known to invest in innovative companies, which account for many of the most successful enterprises in recent decades (Gompers et al., 2020); previous work finds that a dollar of venture capital is about three times more potent in stimulating patenting than a dollar of traditional R&D (Kortum and Lerner, 2000). Patenting is a widely used indicator for innovation output, which complements innovation expenditures like R&D spending and VC investment. We study this collection of measures for innovation, and identify the effects of monetary policy following the standard approach of local projection impulse responses to monetary policy shocks. Our baseline analyses use the Romer and Romer (2004) shocks, which are available for a long sample period from 1969 to 2007; the results are robust to other estimates of monetary policy shocks.

We observe meaningful changes in innovation activities in the years following monetary policy shocks. We normalize the shock to tightening by 100 basis points for illustration (the results are largely symmetric for tightening and easing shocks). First, investment in intellectual property products (IPP) in the national accounts (NIPA) declines by about 1 percent. The magnitude is comparable to the decline in traditional investment in physical assets. R&D spending in Compustat data for public firms declines by about 3 percent. Second, VC investment is more volatile, and declines by as much as 25 percent at a horizon of 1 to 3 years after the monetary policy shock. Third, patenting in important technologies measured by Bloom et al. (2023) declines by up to 9 percent 2 to 4 years after the shock. Interestingly, patenting in other technologies declines by less than patenting in important technologies according to the importance classification in Bloom et al. (2023). An aggregate innovation index constructed by Kogan et al. (2017) using estimates of the economic value of patents also declines by up to 9 percent.[1] Based on estimates by Kogan et al. (2017) about the output and total factor productivity (TFP) sensitivity to the aggregate innovation index, a 9 percent decline in the index can contribute to 1 percent lower real output and 0.5 percent lower TFP 5 years later. These magnitudes are in line with estimates of the social returns to innovation spending (Hall, Mairesse, and Mohnen, 2010; Jones and Summers, 2020).[2] The high returns to innovation and the role of innovation in shaping the productive capacity of

[1] We also compare the impact of monetary policy shocks to that of fiscal policy shocks to provide further perspectives on the magnitude. We use aggregate fiscal shocks due to tax changes constructed by Romer and Romer (2010). We observe that a tax liability increase of 1 percent of GDP is associated with declines in all measures of innovation activities by about the same magnitude as 100 basis point monetary policy tightening.

[2] It is econometrically challenging to directly estimate the impact of monetary policy shocks on output and productivity more than 8 years afterwards (3 years lag for the innovation index and another 5 years lag from innovation to output). In addition, there are a number of other transmission mechanisms of monetary policy that affect the overall impulse response of output to monetary policy shocks. Accordingly, our focus here is to directly trace out the impact of monetary policy shocks on innovation activities, and we rely on previous work about the aggregate implications of innovation to infer the possible long-term output impact.

the economy can make fluctuations of innovation activities even more important than fluctuations of traditional investment in physical assets.[3]

For the transmission mechanism from monetary policy to innovation activities, we find indications that both demand conditions and financial conditions are relevant. First, by decreasing demand, monetary policy tightening can reduce the profitability of developing new products and the incentives to innovate (Shleifer, 1986; Fatas, 2000; Comin and Gertler, 2006; Benigno and Fornaro, 2018). In the data, we observe a stronger decline in both R&D and patenting in more cyclical industries. We also observe that patenting declines after monetary policy tightening among both public and private companies, and among both large and small public companies. To the extent that large public firms have abundant financial resources, the slowdown of innovation activities among these firms is likely driven by reduced demand. Second, monetary policy tightening can affect financial conditions and reduce the appetite for risk taking (Bauer, Bernanke, and Milstein, 2023; Kashyap and Stein, 2023). In the data, we observe that VC investment for both early stage and late stage startups declines after monetary policy tightening. To the extent that early stage startups are still in the product development phase and may not have products coming to the market immediately, reduced funding for them could reflect less appetite for investing in risky endeavors.

Our empirical analyses rely on a collection of innovation measures that can be obtained from existing data, which provide useful indicators of innovation activities in the economy. It is well recognized that capturing all innovation activities is challenging (National Research Council, 2004; Foster et al., 2019; Foster, Grim, and Zolas, 2020), but the mechanisms above can also apply to innovation activities that are more difficult to measure. In addition, although our empirical analyses rely on monetary policy shocks for the purpose of identification, the mechanisms that make innovation activities sensitive to monetary policy shocks should be relevant for the systematic component of monetary policy as well.

Our work has focused on studying the effects of conventional monetary policy. The impact of unconventional monetary policy such as quantitative easing is another interesting question for the past decade. Grimm, Laeven, and Popov (2022) suggest that quantitative easing policies in Europe had a positive effect on the innovation activities of firms whose bonds were eligible for ECB's corporate bond

[3]See Blanchard (2018) for a discussion about how lower capital stock after monetary tightening has limited effects on potential output in a standard model. For example, a 100 basis point monetary policy shock may affect output after 5 years by 0.1 percent through reductions in traditional investment.

purchases. At the same time, Liu, Mian, and Sufi (2022) suggest that when interest rates are very low, further easing may favor industry leaders and result in lower productivity growth. Future empirical work can provide more insights about how unconventional monetary policies and ultra-low interest rates affect innovation activities.

We then turn to the conditions in recent years. Since the rate hikes began in 2022, VC investment has declined substantially from the peak in 2021, by about 30 percent annually. The decline is present in all major sectors (not just in segments that are sometimes perceived as speculative bubbles such as crypto). Investment in generative AI has rebounded in 2023, but largely driven by Microsoft's $10 billion investment in OpenAI. Meanwhile, aggregate R&D in the national accounts has been steady. The real effects of the decrease in VC investment remain to be seen. It is widely recognized that overvaluation was present in the VC market before this downturn (National Venture Capital Association, 2021). Whether venture funding will "return to normal" from overvaluation or experience a persistent slump will become clearer in the coming years. A common question is whether fluctuations in innovation are driven by the rise and fall of excessive investment in wasteful projects. Nanda and Rhodes-Kropf (2013) find that VCs invest more in risky and innovative companies in booms, not just low quality companies. We find that patenting in important technologies responds significantly to monetary policy, suggesting that monetary policy does not just affect the bubble component of innovation cycles.

Over the long run, technological waves can occur from time to time for a variety of reasons, and several major technological waves have survived through adverse macroeconomic environments. For example, during the Second Industrial Revolution and the age of electrification from around the 1890s to around the 1920s, the U.S. economy experienced several large and deep crises such as the panic of 1893 and the panic of 1907. During the Third Industrial Revolution and the age of computerization around the 1970s and the 1980s, the U.S. economy also experienced high inflation and high interest rates due to the oil crisis. Our analyses find that cyclical fluctuations affect innovation activities on an "evolutionary" basis. That said, when technological revolutions occur and innovation activities are several times higher than what takes place in an average decade, adverse macro conditions may not break such waves (even though their magnitude could have been affected on the margin).

Although the data suggest that monetary tightening reduces innovation activities, it is possible that downturns also have cleansing effects by eliminating weak companies (Schumpeter, 1942; Caballero and Hammour, 1994; Foster, Grim, and Haltiwanger, 2016). To the extent that such companies are likely to be technologically underdeveloped and less innovative, the innovation measures above may not capture these potential cleansing effects. Gopinath et al. (2017) suggest that low interest rates worsened misallocation in Southern Europe as capital investment by large firms with high net worth increased by more, due to size-dependent borrowing constraints. Meanwhile, Baqaee, Farhi, and Sangani (2023) suggest that monetary easing can alleviate resource misallocation in a model with variable markups. Studies of business formation also find that economic downturns in the U.S. tend to suppress the emergence of firms with high potential (Ouyang, 2009; Sedláček and Sterk, 2017; Moreira, 2016; Hamano and Zanetti, 2022; Davis and Haltiwanger, 2023). More empirical work on whether (and in which areas) monetary policy may have cleansing effects could be useful.

If monetary policy affects innovation, what are the implications for the conduct of monetary policy? A small and growing set of theoretical models consider the design of optimal monetary policy with endogenous productivity (Benigno and Fornaro, 2018; Ikeda and Kurozumi, 2019; Garga and Singh, 2021; Queralto, 2022; Fatás and Singh, 2022; Fornaro and Wolf, 2023). Our focus is to present empirical facts, and optimal policy analysis is beyond the scope of this paper. We summarize several questions about policy implications that often come up in light of our empirical evidence. More work in the future can help us better understand these issues.

First, should monetary policy be more accommodative on average if innovation is undersupplied (due to high social externalities)? At the moment, we are mindful of the well known lesson that efforts seeking to perennially stimulate the economy with monetary easing may be ineffective or counterproductive (Friedman, 1968; Lucas, 1976). Second, should monetary policy be more countercyclical to stabilize innovation? Several papers suggest that stabilizing innovation is beneficial (Barlevy, 2004; Aghion, Farhi, and Kharroubi, 2012). We hope that our evidence on the sensitivity of innovation to monetary policy can inform future analyses. Third, given that monetary policy has easing and tightening periods, do their effects cancel out? As discussed above, monetary easing and tightening could be useful for stabilizing innovation in response to other shocks (e.g., demand or financial shocks), so the issue is not just about monetary policy actions in different directions offsetting themselves. In addition, as Blanchard (2018) writes, the objective is to study “the size and persistence of the effects of monetary policy on potential output, not their permanence" (permanent effects are inevitably difficult to pin down). Finally, can other policies address fluctuations in innovation so that monetary policy maintains a simpler focus? Fiscal policy is a standard option, but it may face budgetary constraints and implementation challenges (e.g., selecting the innovation activities to subsidize and making frequent adjustments).

In summary, the evidence shows that the effects of monetary policy on innovation activities and the potential longer-term consequences deserve more attention. Monetary policy can influence production activities in many important ways. In the minutes and transcripts of the FOMC, discussions about the impact of monetary policy on investment typically focus on traditional capital expenditures on physical assets; in monetary economics, the word "innovation" typically occurs in the context of "monetary policy innovation." Given the significance of production innovation and technological advancement for economic progress, it would be valuable to consider this dimension, and to better understand its implications for the conduct of monetary policy.

II. Monetary Policy Shocks and Innovation Activities

This section presents our main results about the effects of monetary policy on innovation activities. We provide the findings in Section 2.1, discuss the mechanisms behind the evidence in Section 2.2, and make a comparison with the effects of fiscal policy in Section 2.3.

II.A. Main Results

We examine the impulse response of innovation activities to monetary policy shocks. Our baseline tests use quarterly Romer and Romer (2004) shocks with updates by Ramey (2016) and Wieland and Yang (2020), which cover a long time period from 1969 to 2007. The results are similar using the refinement of Romer and Romer (2004) shocks by Aruoba and Drechsel (2023), or high frequency shocks (which start later in the 1990s). The monetary policy shocks aim to capture variations in the Federal Funds rate that are not explained by the prevailing economic conditions, in order to isolate the influence of monetary policy on subsequent economic activities. We use standard Jordà (2005) local projections, and the impulse response plots present the coefficients from regressing future outcomes on the monetary policy shock; our empirical specifications follow Ramey (2016). We normalize the shock to tightening by 100 basis points for illustration; so far we do not find the results to be significantly asymmetric for tightening and easing shocks.

Figure 1, Panel A, begins with the impulse response of standard outcome variables, including quarterly real GDP, unemployment, and real investment in physical assets (nonresidential investment in structure and equipment plus residential investment) from the national accounts (NIPA).[4] Panel B studies several measures of innovation spending, including quarterly real investment in intellectual property products (IPP) from the national accounts (which includes spending on R&D), and quarterly real VC investment from VentureXpert (now in the Refinitiv Private Equity database).[5] We also separate VC investment into early stage deals and late stage deals. For all regressions in this section, we control for 4 lags of the outcome variable, the Federal Funds rate, log real GDP, log CPI, the unemployment rate, and the excess bond premium.

We observe that investment in IPP declines by about 1 percent in the following 2 years, broadly in line with the magnitude of the decline for traditional investment in physical assets. The NIPA measure of quarterly IPP investment may be overly stable since the underlying sources are annual surveys of firms' innovation activities (such as the Business R&D and Innovation Survey and the Survey of Industrial Research and Development), and NIPA then interpolates annual data to construct quarterly series (Crawford et al., 2014).[6] In Panel A of Figure A1, we also provide impulse responses based on firm-level quarterly real R&D spending for public companies using Compustat data. Quarterly R&D spending in Compustat was sparse before 1990, so the time span is shorter. In addition, incomplete R&D reporting in financial statements can generate missing observations in Compustat data (Koh and Reeb, 2015), so we use the Compustat analysis as supplementary information. We observe that R&D spending among Compustat firms declines by about 3 percent 2 to 3 years after the monetary policy tightening shock. The magnitude is broadly similar to the sensitivity of Compustat firm-level R&D

[4]We use Eicker–Huber–White standard errors following the recommendations of Montiel Olea and Plagborg-Møller (2021). Newey and West (1994) standard errors produce similar results.

[5]We use VC investment data starting in 1980 because VC was rare before then. The results are stronger if we include earlier data from VentureXpert.

[6]Before 1990, the quarterly estimates are interpolated assuming no quarterly patterns. For 1991 to 2007, current-dollar business R&D is interpolated using a seasonally adjusted composite series from the quarterly census of employment and wages (QCEW) from the Bureau of Labor Statistics (BLS). The composite quarterly indicator is constructed by weighting three-quarter moving averages of industry-specific QCEW wage data. After 2008, quarterly business R&D is interpolated using seasonally adjusted R&D expenses reported on publicly traded companies' quarterly financial statements. The quarterly investment in equipment and structures does not have this interpolation issue because such investment can be directly measured using shipment and construction data (Holt, 2014).

spending to interest rates in Döttling and Ratnovski (2023).[7] For VC investment, which is more volatile, the impulse response is even larger in magnitude. For up to 12 quarters after the tightening shock, quarterly VC investment declines by as much as 25 percent (though the coefficients are not estimated very precisely due to noise in historical VC investment data). The decline is observed for both early stage and late stage VC deals.

Figure 2 turns to technological diffusion and advancement measured using patent data. Recent work by Bloom et al. (2023) categorizes around 300 types of important technologies that emerged since 1976 (such as cloud computing and electric vehicles). They first classify different types of technologies using bigrams in patent text, and then select important technologies as those that are frequently mentioned in companies' earnings calls (by more than 100 times between 2002 and 2019). We calculate the number of patent filings associated with these important technologies each quarter, and use local projection regressions to study the impulse response to monetary policy shocks. In Panel A, we observe that patenting in these important technologies declines by as much as 9 percent about 3 to 4 years after the shock. This time frame is consistent with previous findings that the R&D process takes 2 to 3 years (Mansfield et al., 1971; Ravenscraft and Scherer, 1982; Jones and Summers, 2020), and that the effects of other shocks (e.g., credit supply) on patent filings start to emerge after 1 or 2 years (Amore, Schneider, and Žaldokas, 2013; Chava et al., 2013; Cornaggia et al., 2015).

We also observe that patenting in important technologies appears more affected than patenting in general. In Panel B of Figure 2, we perform the same regressions in Panel A but for technologies that are outside of the set of important technologies. The decline we observe is only around half as much as that in Panel A. Similarly, we do not find a clear response for the total number of all patents. One possibility is that patenting in these important technologies captures the adoption of new technologies. Companies may be less (more) eager to spend effort and resources to adopt them following monetary policy tightening (easing), due to changes in financial conditions and the profitability of innovation that we will discuss more in Section 2.2. In comparison, total patent counts for instance can be driven by refinement of old technologies or random explorations, which are less cyclical.

For patenting associated with the important technologies in Bloom et al. (2023), Figure 3 provides

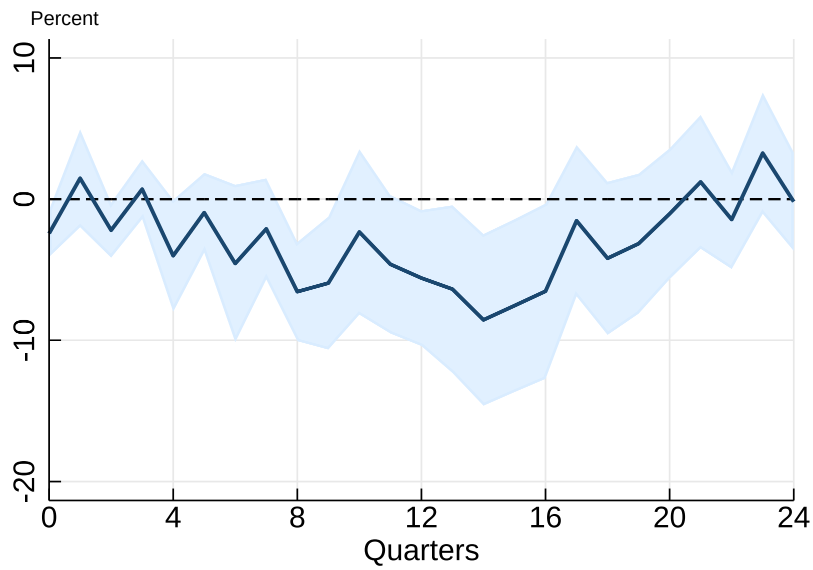
[7] Intangible investment studied in Döttling and Ratnovski (2023) also includes Selling, General and Administrative Expenses (SG&A), which may capture other types of intangible investment that are not necessarily related to innovation (e.g., branding).

Figure 1. Impulse Response of Economic and Innovation Activities to Monetary Policy Shock

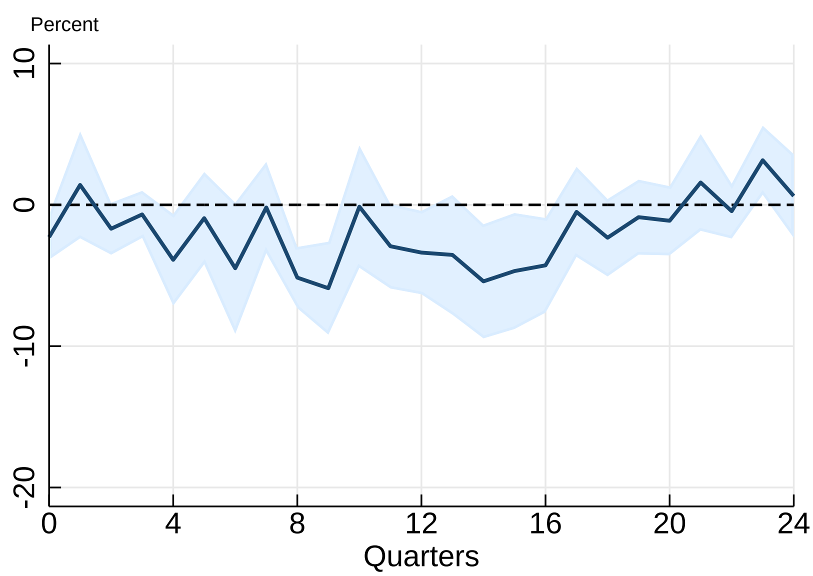
Notes: Panel A shows the impulse response of standard outcome variables, including quarterly Federal Funds rates, log real GDP, unemployment, and log real physical asset investment from the national accounts (nonresidential investment in structure and equipment plus residential investment), to a 100 basis point Romer and Romer (2004) monetary policy shock. Panel B shows the impulse response of innovation spending measures, including quarterly log real investment in Intellectual Property Products (IPP) from the national accounts, as well as log real total, early stage, and late stage venture capital (VC) investment. We estimate Jordà (2005) local projections $x_{t+h} = \alpha + \beta mps_t + \gamma z_t + \epsilon_t$, and plot the regression coefficient β on the monetary policy shock (the solid line). The control variables z_t include 4 lags of the outcome variable, 4 lags of the monetary policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, and the excess bond premium (Gilchrist and Zakrajšek, 2012). Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021). The shaded area represents the 90% confidence interval.

Figure 2. Impulse Response of Patent Filings in Important Technologies to Monetary Policy Shock

Panel A: Important Technologies

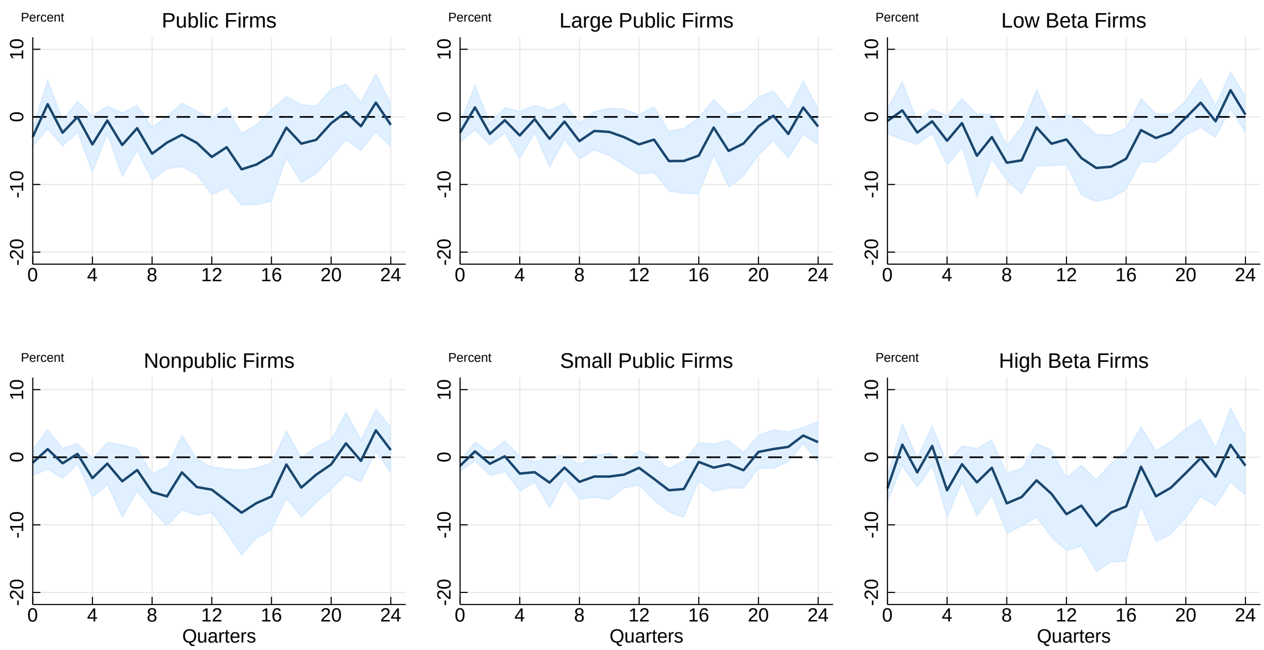


Panel B: Other Technologies



Notes: Panel A shows the impulse response of patent filings associated with the important technologies to a 100 basis point Romer and Romer (2004) monetary policy shock. Panel B shows the impulse response of patent filings associated with other technologies. We estimate Jordà (2005) local projections $x_{i,t+h} = \alpha_i + \beta mps_t + \gamma z_t + \epsilon_{i,t}$, and plot the regression coefficient β on the monetary policy shock (the solid line). The outcome variable $x_{i,t+h}$ is the log number of patents filed in technology i in quarter $t+h$. The control variables z_t include 4 lags of the outcome variable, 4 lags of the monetary policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, the excess bond premium (Gilchrist and Zakrajšek, 2012). Technology fixed effects and technology age fixed effects (number of years since the earliest patent filing in the technology) are included. Standard errors are Driscoll and Kraay (1998) with a bandwidth of 20. The shaded area represents the 90% confidence interval.

Figure 3. Impulse Response of Different Types of Patents to Monetary Policy Shock



Notes: This figure shows the impulse response of patents associated with the important technologies filed by the public and private firms, large public and small public firms, and patents in less and more cyclical industries (based on estimates of asset beta by scaling equity beta from stock returns with leverage), to a 100 basis point Romer and Romer (2004) monetary policy shock. We estimate Jordà (2005) local projections $x_{i,t+h} = \alpha_i + \beta mps_t + \gamma z_t + \epsilon_{i,t}$, and plot the regression coefficient β on the monetary policy shock (the solid line). The outcome variable $x_{i,t+h}$ is the log number of patents filed in technology i in quarter $t+h$. The control variables z_t include 4 lags of the outcome variable, 4 lags of the monetary policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, the excess bond premium (Gilchrist and Zakrajšek, 2012). Technology fixed effects and technology age fixed effects (number of years since the earliest patent filing in the technology) are included. Standard errors are Driscoll and Kraay (1998) with a bandwidth of 20. The shaded area represents the 90% confidence interval.

a further breakdown for those filed by public and private firms, large public and small public firms (asset size above and below median), and patents in less and more cyclical industries (asset beta below and above median). We observe that patenting declines in all these cases, and the decline is larger in more cyclical industries. These patterns are consistent with the impulse response of R&D spending in Compustat data for different types of firms, shown in Panel B of Figure A1. There we also observe a stronger response for firms that are more cyclical. We will use these results to shed further light on the underlying mechanisms in Section 2.2.

Finally, Figure 4 examines the aggregate innovation index constructed by Kogan et al. (2017). In this case, we also observe a decline in the innovation index by up to 9 percent 2 to 3 years following the shock. Based on the estimates in Kogan et al. (2017), a 9 percent decline in the innovation index for over a year could lead to lower output by 1 percent and TFP by 0.5 percent 5 years later.[8] These magnitudes are consistent with estimates of the social returns to innovation spending (Hall, Mairesse, and Mohnen, 2010; Jones and Summers, 2020). For instance, many studies estimate that 1 dollar of innovation spending generates about 10 dollars of social returns. R&D spending is about 2.5 percent of GDP, and VC investment is about 0.75 percent of GDP. A 2 percent decrease in R&D spending and a 25 percent decrease in VC investment would imply lower output by over 2 percent.[9] The high returns to innovation and the role of innovation in shaping the productive capacity of the economy can make fluctuations of innovation activities more important than fluctuations of traditional investment in physical assets. As Blanchard (2018) explains, lower capital stock after monetary tightening has a relatively limited impact on potential output in standard models. For example, a 100 basis point monetary policy shock may affect output after 5 years by around 0.1 percent through changes in traditional investment.[10]

It is econometrically challenging to directly estimate the impact of monetary policy shocks on output and productivity over 8 years afterwards (3 years lag for the innovation index and another 5 years lag from innovation to output). In addition, there are a number of other transmission mechanisms of monetary policy that affect the output response (Christiano, Eichenbaum, and Evans, 2005; McKay and Wieland, 2021; Baqaee, Farhi, and Sangani, 2023). Accordingly, our focus is to directly trace out the effects of monetary policy shocks on innovation activities, and we rely on previous work about the aggregate implications of innovation to infer the longer-term output impact of this channel.

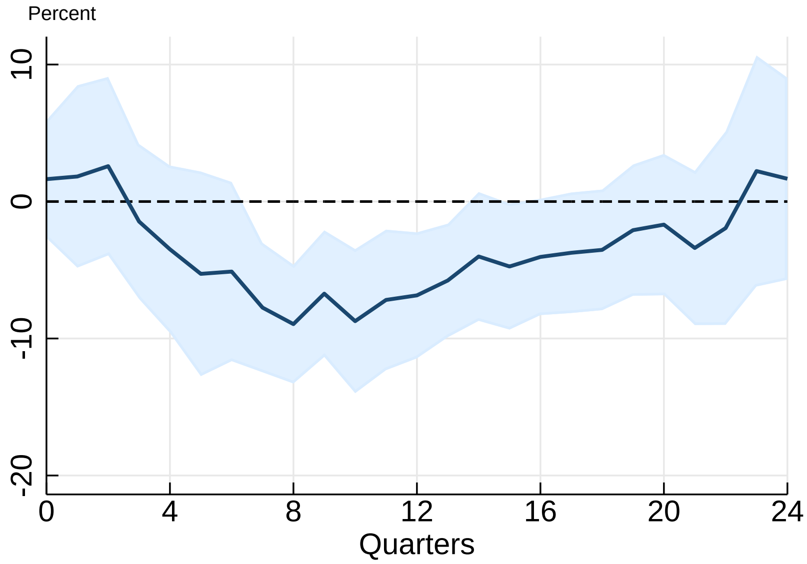
One possible concern is that monetary policy shocks are not fully exogenous. If the shocks have endogenous elements, these imperfections can bias against finding significant real effects. For example, if monetary policy tightens when the economy overheats, it would be harder to find negative real effects. In the appendix (Figures A2 to A4), we also present analyses using the Aruoba and Drechsel (2023)

[8]The output response to the innovation index analyzed in Kogan et al. (2017) does not specify the sources for the variations in the innovation index. Accordingly, our imputations assume that the changes in innovation due to monetary policy have similar output consequences as the typical changes in innovation.

[9]Jordà, Singh, and Taylor (2023) perform long-run cross-country analyses to identify exogenous monetary policy fluctuations using the trilemma, where a country that pegs its currency needs to follow interest rates set by the base country. They estimate that a 100 basis point tightening shock (induced by interest rate changes of the base country) leads to 5 percent lower output after 8 years. The magnitude can be larger in their analyses because they do not focus just on the innovation channel for the long-run effects of monetary policy on output. It is also possible that the effects are larger outside of the U.S.

[10]Some innovation expenditures, such as VC investment, seem much more volatile than traditional investment in physical assets. Meanwhile, other innovation expenditures, such as R&D spending, seem to fluctuate less, which could be due to economic properties Crouzet and Eberly (2019) or measurement (see footnote 6). For the same amount of fluctuation, changes in innovation activities appear to contribute to more persistent effects of monetary policy, given the long time frame of innovation and the potential impact of innovation on productivity.

Figure 4. Impulse Response of Innovation Index to Monetary Policy Shock



Notes: This figure shows the impulse response of the aggregate innovation index by Kogan et al. (2017) to a 100 basis point Romer and Romer (2004) monetary policy shock. We estimate Jordà (2005) local projections $x_{t+h} = \alpha + \beta mps_t + \gamma z_t + \epsilon_t$, and plot the regression coefficient β on the monetary policy shock (the solid line). The control variables z_t include 4 lags of the outcome variable, 4 lags of the monetary policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, and the excess bond premium (Gilchrist and Zakrajšek, 2012). Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021). The shaded area represents the 90% confidence interval.

refinement of the Romer and Romer (2004) shocks. Aruoba and Drechsel (2023) use textual analyses of FOMC documents to further remove the responses of the Federal Funds rate to economic conditions. We observe similar results with slightly larger magnitude. In general, further refinement of monetary policy shocks tends to generate stronger real effects (Bauer and Swanson, 2023).

II.B. Mechanisms

Research on innovation activities points to at least two mechanisms for the impact of monetary policy on innovation. First, by decreasing demand, monetary policy tightening can reduce the profitability of developing new products and the incentives to innovate. Second, monetary policy tightening can affect financial conditions and reduce the appetite for risk taking. The empirical results above suggest that both mechanisms are relevant.[11]

[11] One might also ask about the relevance of the user cost channel. Previous studies of traditional investment in physical assets have found limited effects of the plain vanilla user cost channel (Bernanke and Gertler, 1995; Caballero, 1999), and there are reasons to think that some innovation spending that depreciates more quickly (e.g., R&D) could be less responsive to user costs (Crouzet and Eberly, 2019; Döttling and Ratnovski, 2023). In addition, Panel A of Figure 1 suggests that the

For the relevance of demand, we observe in Figure 3 a stronger response of patenting to monetary policy shocks for more cyclical industries (i.e., industries with higher asset beta), where demand is likely more sensitive to economic conditions. Their R&D spending also declines by more as shown in Panel B of Figure A1. In addition, we see that the decline in innovation activities occurs among both public and private firms, and among both large public and small public firms. To the extent that large public firms are less affected by financial conditions, the slowdown in technological development among these companies is likely driven by reduced demand.

For the relevance of financial conditions, Panel B of Figure 1 shows that early stage VC investment declines after monetary policy tightening. To the extent that early stage startups are still in the product development phase and may not have products coming to the market immediately, the reduction of funding for them could reflect less appetite among investors for risky undertaking. Figure A5 shows that the excess bond premium is higher by up to 10 basis points for a year after the tightening shock, and the NASDAQ index is lower by 8 percent for 3 to 4 years. Figure A6 shows that when the excess bond premium increases by 100 basis points, innovation activities in the following years decline significantly. Based on these magnitudes, a 10 basis point change in the excess bond premium following our baseline monetary policy shock can partly account for the changes in innovation activities.[12]

Our empirical analyses need to rely on the readily measurable metrics of innovation, which serve as useful indicators of innovation activities in the economy. It is challenging to measure all innovation activities, but these mechanisms can also apply to innovation activities that are more difficult to measure. We also rely on monetary policy shocks for empirical identification. The mechanisms that make innovation activities sensitive to monetary policy shocks should be relevant for the systematic component of monetary policy as well. In particular, the systematic component of monetary policy affects both aggregate demand and financial conditions, which may then transmit to innovation activities.

monetary policy shocks are temporary. In the absence of changes in financial conditions, the user costs would only change by about one year.

[12] The excess bond premium may have a forward-looking component, so there can be caveats for interpreting it as a pure shock to financial conditions.

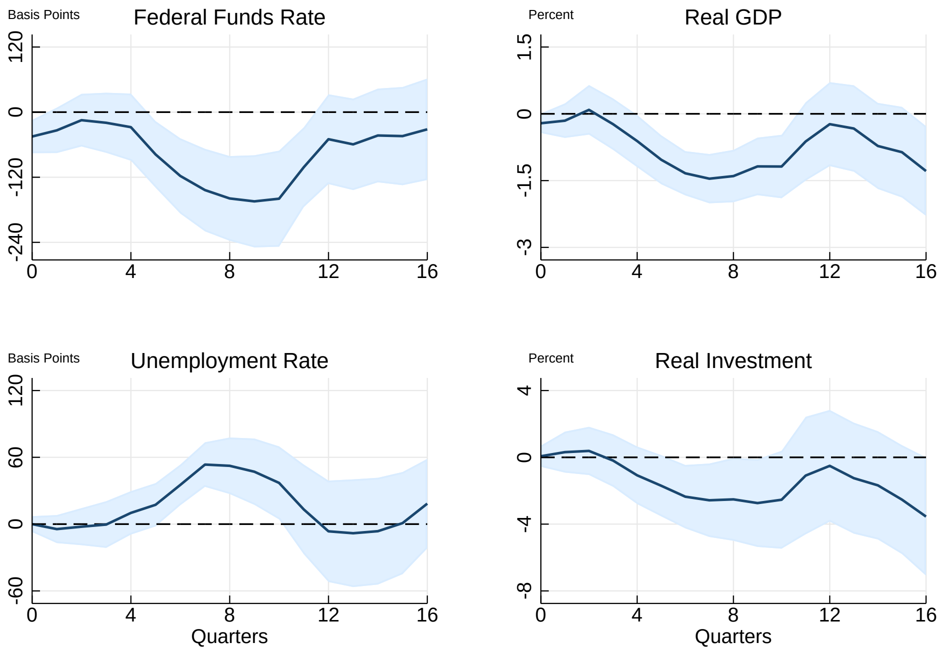
II.C. Comparison with Fiscal Policy Shocks

To provide further perspectives on the magnitude of the changes in innovation activities following monetary policy shocks, we present a comparison with the response of innovation to fiscal policy shocks. Although empirical analyses of how monetary policy affects innovation are scarce, a large literature has investigated the impact of fiscal policy on innovation, covering tax changes, military spending, and specific government programs (Bloom, Griffith, and Van Reenen, 2002; Howell, 2017; Azoulay et al., 2019; Akcigit et al., 2022; Myers and Lanahan, 2022; Kantor and Whalley, 2022; Cloyne et al., 2022; Antolin-Diaz and Surico, 2022). Many of these studies document that fiscal policy has significant effects on innovation. For parsimony, we provide a simple comparison of the impulse response of innovation activities to monetary policy shocks documented above with the response to fiscal policy shocks in the form of tax changes. Tax changes can directly affect a large set of firms, facilitating the comparison with monetary policy shocks, whereas the direct effect of military spending and particular government programs may concentrate on a subset of firms. We use the aggregate fiscal shocks due to tax changes constructed by Romer and Romer (2010), who read historical records to classify exogenous tax changes that are not related to the current state of the economy. We present the results in Figures 5 and 6 using the same empirical specification and the same sample period as the corresponding analyses in Section 2.

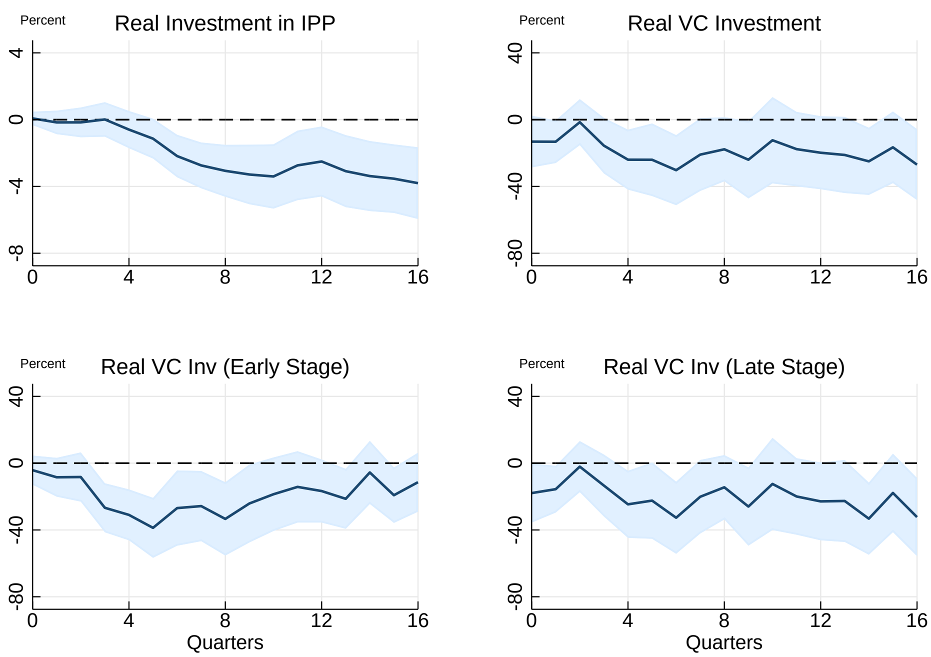
With a tax change that increases tax liabilities by 1 percent of GDP, we observe that real GDP declines by about 1.5 percent after 2 to 3 years, and investment in both traditional physical assets and intellectual property declines by around 3 percent. VC investment (in both early stage and late stage deals) declines by about 25 percent for several years. Patenting in important technologies and the innovation index decline by 5 to 10 percent. Overall, the magnitude is similar to a 100 basis point monetary policy shock shown in Section 2.1. These results further help us put into perspective the effect of monetary policy shocks on innovation activities.

Figure 5. Impulse Response of Economic and Innovation Activities to Fiscal Policy Shock

Panel A: Standard Outcome Variables

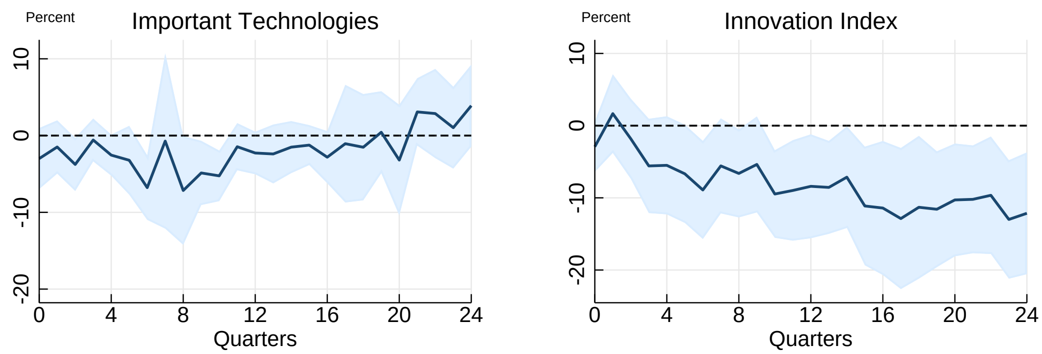


Panel B: Innovation Spending



Notes: Panel A shows the impulse response of standard outcome variables, including quarterly Federal Funds rates, log real GDP, unemployment, and log real physical asset investment from the national accounts, to a 1 percent increase in tax liabilities to GDP from Romer and Romer (2010). Panel B shows the impulse response of innovation spending measures, including quarterly real investment in Intellectual Property Products (IPP) from the national accounts, as well as real total, early stage, and late stage venture capital (VC) investment. The control variables include 4 lags of the outcome variable, 4 lags of the fiscal policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, and the excess bond premium (Gilchrist and Zakrajšek, 2012). Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021). The shaded area represents the 90% confidence interval.

Figure 6. Impulse Response of Patenting and Innovation Index to Fiscal Policy Shock



Notes: This figure shows the impulse response of patent filings associated with the important technologies and the aggregate innovation index constructed by Kogan et al. (2017) to a 1 percent increase in tax liabilities to GDP from Romer and Romer (2010). The control variables include 4 lags of the outcome variable, 4 lags of the fiscal policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, the excess bond premium (Gilchrist and Zakrajšek, 2012). The regressions using the panel of important technologies include technology fixed effects and technology age fixed effects (number of years since the earliest patent filing in the technology). Standard errors are Driscoll and Kraay (1998) with a bandwidth of 20 for patenting in important technologies, and Eicker–Huber–White for the innovation index. The shaded area represents the 90% confidence interval.

III. Discussion

We discuss three sets of additional topics in this section. First, we present an overview of the current conditions for innovation investment in Section 3.1. Second, we summarize the long-run evolution of innovation activities in Section 3.2. Third, we discuss potential policy implications related to the effects of monetary policy on innovation in Section 3.3.

III.A. Current Conditions

Since the start of rate hikes in 2022, the venture capital market has cooled down substantially. In the following, we discuss recent developments in innovation investment.

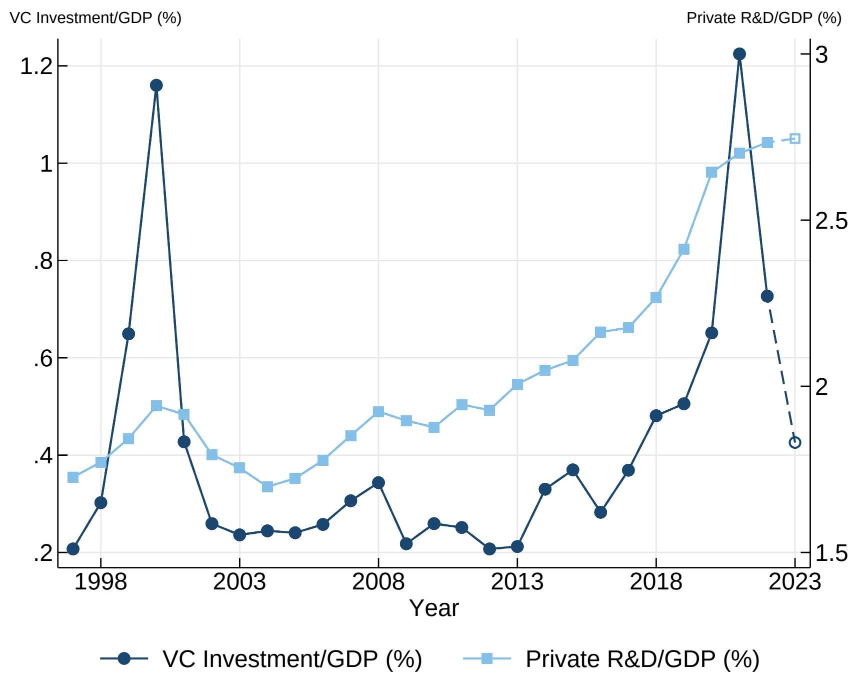
Figure 7 presents the general trends in the past few decades. Panel A shows VC investment, as well as R&D investment in the national accounts, as a share of GDP. Panel B shows the annual growth rate of VC investment and R&D investment in the national accounts. Both series increased around 2000, declined in the early 2000s, and rose steadily in the past decade until 2022. Since 2022, VC investment has fallen by around 30 percent annually. R&D in the national accounts has continued to grow. Overall, the growth of VC investment and R&D spending in NIPA are 60% correlated, but VC investment is much more volatile, in line with higher sensitivity of startup activities to business conditions. Figure 8 presents the trends in VC investment by industry segment based on PitchBook data. Panel A shows that the recent decline is observed in all major industry groups (not just in segments that are sometimes perceived as speculative bubbles such as crypto). Panel B shows that the area of generative AI in 2023 is one exception, but the increase is largely driven by Microsoft's $10 billion investment in OpenAI.

It remains to be seen whether the recent slowdown in VC activities will be transitory or persistent like in the early 2000s. One common question is whether these episodes represent declines of socially valuable innovation, or corrections of bubbles and excessive investment. On the one hand, economics research generally holds the view that innovation is undersupplied due to high externalities (Jones and Williams, 1998; Bloom, Schankerman, and Van Reenen, 2013). Previous work also finds that innovation downturns have negative effects. Bianchi, Kung, and Morales (2019) suggest that the 2001 recession could have contributed to persistent growth slowdown. Nanda and Rhodes-Kropf (2013) suggest that VCs fund companies that are riskier but more innovative in hot markets, instead of systematically making wasteful investment. On the other hand, many examples point to overvaluation during the dotcom boom, and at least some companies without viable businesses received abundant financing. In our data, monetary policy affects important technologies more than ordinary technologies, as shown in Figure 2. In other words, shifts in monetary policy appear to influence innovation activities that are socially relevant rather than simply the bubble component.

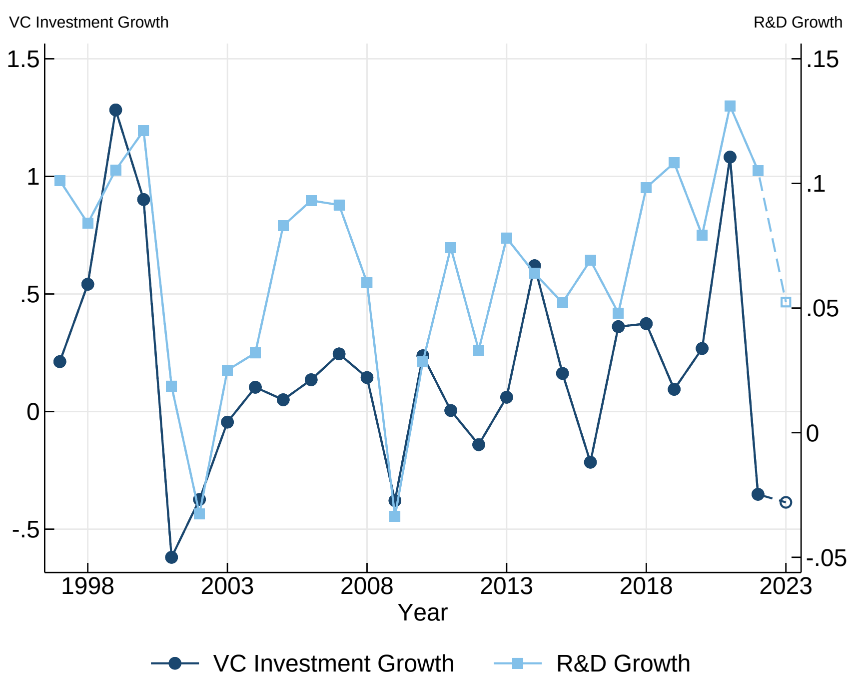
Our analyses in Section 2.1 study the effects of conventional monetary policy using monetary policy shocks data up to 2007. The impact of unconventional monetary policy such as quantitative easing is another interesting question for the past decade. Grimm, Laeven, and Popov (2022) suggest that quantitative easing in Europe had a positive effect on the innovation activities of firms whose bonds were eligible for the ECB's corporate bond purchases. At the same time, Liu, Mian, and Sufi (2022) suggest that when interest rates are very low, further easing may favor industry leaders and result in lower productivity growth. Future empirical work can shed more light on how unconventional monetary policy and ultra-low interest rates affect innovation activities.

Figure 7. Recent Trends in Innovation Investment

Panel A: Annual VC Investment and R&D Investment as a Share of GDP



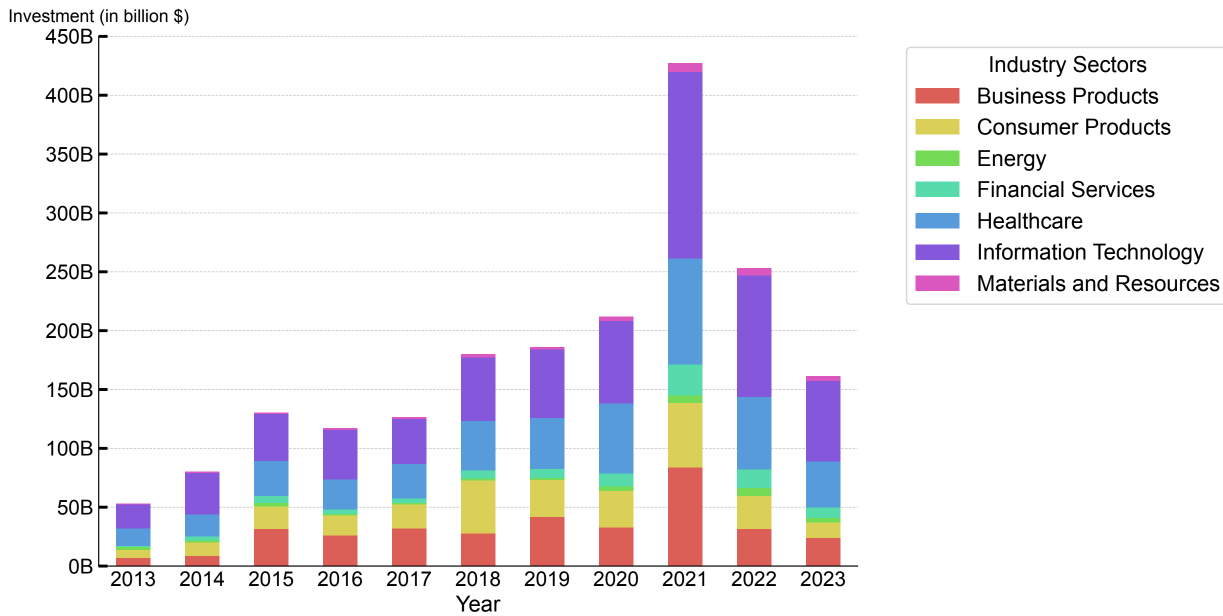
Panel B: Annual Growth of VC Investment and R&D Investment



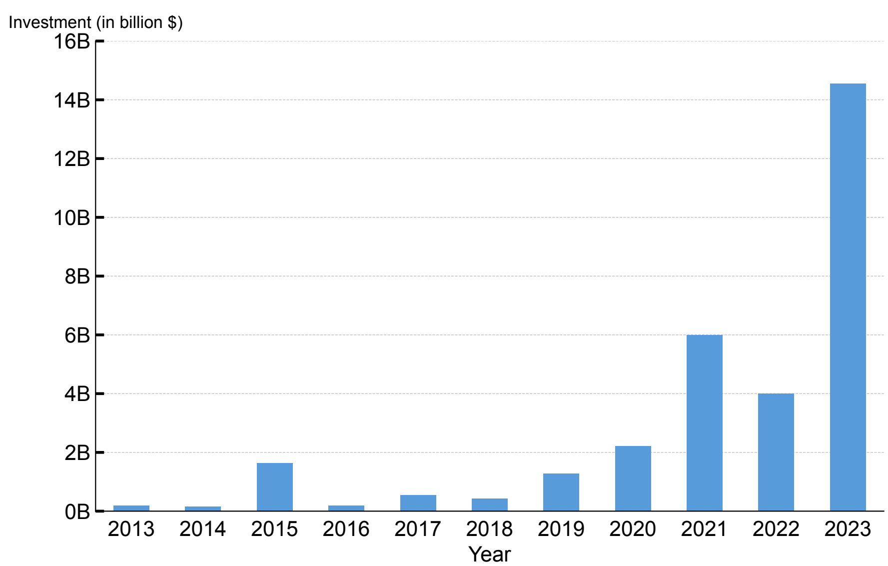
Notes: Panel A shows VC investment as a share of GDP, as well as R&D investment in the national accounts as a share of GDP. Panel B shows the annual growth rate of VC investment and R&D investment in the national accounts. Data for 2023 use annualized rates based on Q1 and Q2.

Figure 8. Recent Trends in VC Investment by Industry

Panel A: VC Investment in Major Industry Groups



Panel B: VC Investment in Generative AI



Notes: Panel A shows annual VC investment in major industry segments. Panel B shows annual VC investment in generative AI. Data come from PitchBook. Data for 2023 include Q1 and Q2.

III.B. Long-Run Evolution of Innovation Activities

Our analyses in Section 2.1 find that monetary policy can influence innovation activities. At the same time, technology may progress for a variety of other reasons, and from time to time technological advancement may experience revolutionary waves. Over the past 150 years, adverse macroeconomic shocks happened to have hit during several technology waves, but these waves appeared to be able to withstand difficult times. For example, during the Second Industrial Revolution and the age of electrification from around the 1890s to around the 1920s (Jovanovic and Rousseau, 2005), the U.S. economy experienced the panic of 1893 and the panic of 1907. Rapid electrification and industrialization still took place despite these negative shocks. During the Third Industrial Revolution and the age of computerization around the 1970s and the 1980s, the U.S. economy experienced high inflation and high interest rates due to the oil crisis, but substantial advancement in information technology still took place. According to some analyses of productivity as well as patenting activities, innovation activities were vibrant in the 1930s even during the Great Depression (Field, 2003; Kelly et al., 2021).

Although it is challenging to precisely measure the magnitude of the technological waves, it seems plausible that the eras of technological revolutions witnessed changes that are several times larger than what happens in an average decade. Adverse economic conditions may reduce the magnitude of activities by some fraction, but the waves remain substantial. Given that revolutionary episodes are infrequent and difficult to quantify, we do not formally test the factors that could predict technological waves. It is an interesting question to better understand the extent to which cyclical conditions play a role in technological revolutions. At the moment, our reading of the evidence is that monetary policy can affect innovation activities on an “evolutionary" basis, and it remains to be seen whether it has any role in innovation activities on a “revolutionary" basis.

III.C. Policy Implications

If monetary policy affects innovation, what might be the policy implications? A small set of theoretical models analyze optimal monetary policy with endogenous innovation and productivity. Several questions may emerge in light of the connection between monetary policy and innovation. First, should monetary policy be more accommodative on average, to the extent that innovation is undersupplied (due to high social externalities)? Recent analyses suggest that, depending on the properties of shocks, optimal policy may follow inflation targeting outside the zero lower bound, or may set inflation above target when subsidies for innovation fall short of the externalities (Garga and Singh, 2021; Queralto, 2022). More work in the future can better understand this issue, and we are also mindful of the well known lesson that efforts seeking to perennially stimulate the economy with monetary easing may be ineffective or counterproductive (Friedman, 1968; Lucas, 1976).

Second, should monetary policy be more countercyclical? An earlier study by Aghion, Farhi, and Kharroubi (2012) postulates that countercyclical stabilization is especially important when cyclical fluctuations affect innovation and growth. They conduct cross-country empirical analyses and find that countries with more countercyclical monetary policies experience higher growth, especially in industries that appear to be more financially constrained. Several models that examine endogenous productivity and hysteresis also highlight the significance of output stabilization for optimal monetary policy (Ikeda and Kurozumi, 2019; Fatás and Singh, 2022; Galí, 2022). Our empirical evidence on how much innovation activities respond to monetary policy can provide more information for future analyses about the effects of output stabilization.

Third, monetary policy has easing and tightening periods; do their effects on innovation cancel out? As discussed above, monetary easing and tightening could be useful for stabilizing innovation in response to other shocks (e.g., demand shocks or financial shocks); several studies emphasize that facilitating recoveries from crises that reduce innovative capacity is beneficial for the medium term. The issue is not just about monetary policy actions in different directions offsetting themselves. In addition, as Blanchard (2018) writes, the objective is to understand "the size and persistence of the effects of monetary policy on potential output, not their permanence." Our work also focuses on the potential persistent effects, not necessarily permanent effects in the very long run (which would be difficult to pin down).

Finally, can other policies address fluctuations in innovation activities instead of monetary policy, or in response to the impact of monetary policy? For example, as recent research points to the impact of monetary policy on financial stability, many studies analyze the feasibility of using macroprudential policy to target financial stability while monetary policy focuses on macroeconomic stability. For innovation activities, an analogous question is whether other tools can support and stabilize innovation activities. A number of measures may support innovation activities during economic downturns. Standard toolbox points to various programs that can provide grants or subsidies. Recent work suggests that fiscal policies could push the economy out of a stagnation trap (Benigno and Fornaro, 2018), or support business investment and relax supply side constraints in light of monetary policy tightening during disinflations (Fornaro and Wolf, 2023). Relaxing supply side constraints may also reduce marginal costs and inflationary pressures. A well-functioning system for restructuring viable companies in financial distress can be useful too, especially given the importance of specialized physical, human, and organizational capital that make liquidating these firms especially costly. Future work can shed more light on whether innovation-related issues can be addressed fully with other policies, so that monetary policy can be insulated from considering its effects on innovation.

Overall, given the significance of innovation activities for economic progress, it would be valuable to investigate the role of monetary policy in this domain in academic research and policy analyses, and to better understand the implications for the conduct of monetary policy.

IV. Conclusion

We document the response of innovation activities to monetary policy using a collection of measures for innovation. The results suggest that monetary policy could have a persistent influence on the productive capacity of the economy, in addition to the well-recognized near-term effects on economic outcomes. Developments in the past several years highlight the relevance of these issues. Rising interest rates since 2022 have been accompanied by a substantial decline in venture capital investment. Meanwhile, recent breakthroughs in AI raise the hope that another technological revolution could be on the horizon, and maximizing the benefit of the technological breakthroughs is important.

We do not think our findings necessarily imply that monetary policy should be more dovish. It is well recognized that efforts seeking to perennially stimulate the economy with monetary easing can be ineffective or counterproductive (Friedman, 1968; Lucas, 1976). In addition, as recent research points to the effects of monetary policy on a growing list of economic outcomes, it seems challenging for monetary policy alone to balance all these dimensions. One possibility is to apply other policies that relax supply side constraints and support innovation during economic downturns (e.g., in light of financial crises) or when monetary policy tightening is needed (e.g., in light of inflationary pressures). More work in the future can illuminate the implications that arise from the effects of monetary policy on innovation.

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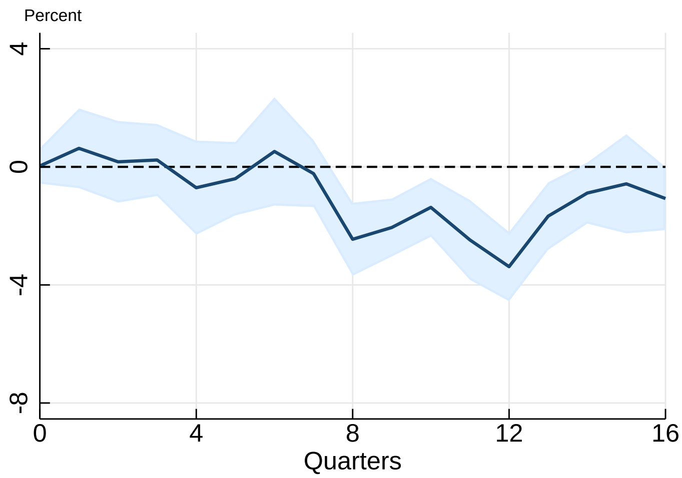
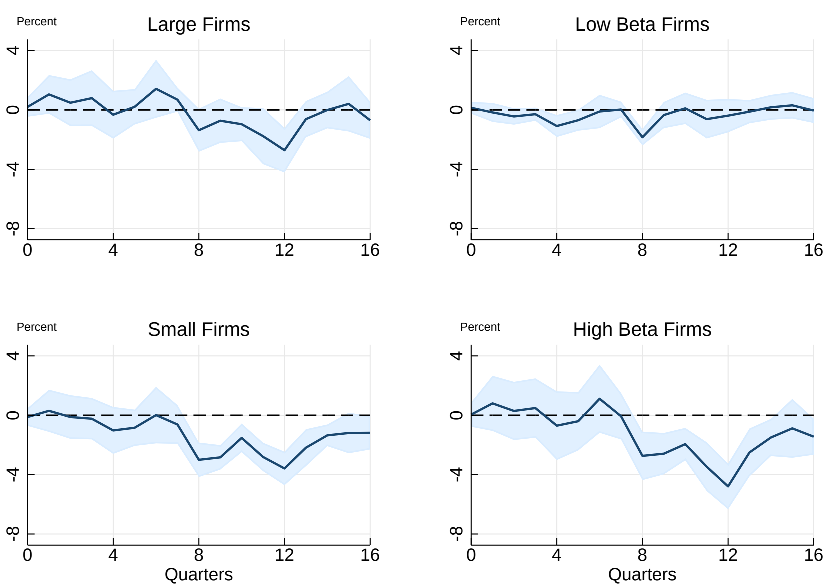
Appendix

Figure A1. Impulse Response of R&D Spending among Public Firms to Monetary Policy Shock

Panel A: All Firms



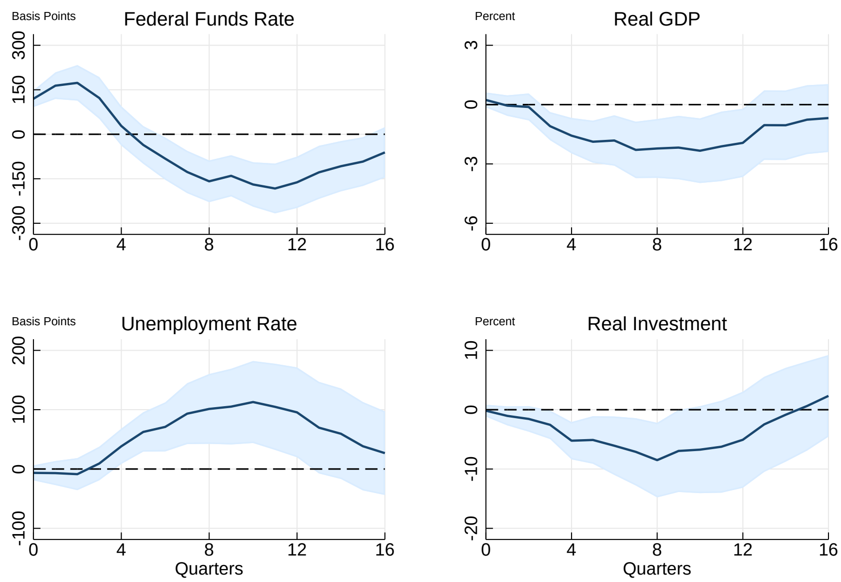
Panel B: Different Types of Firms



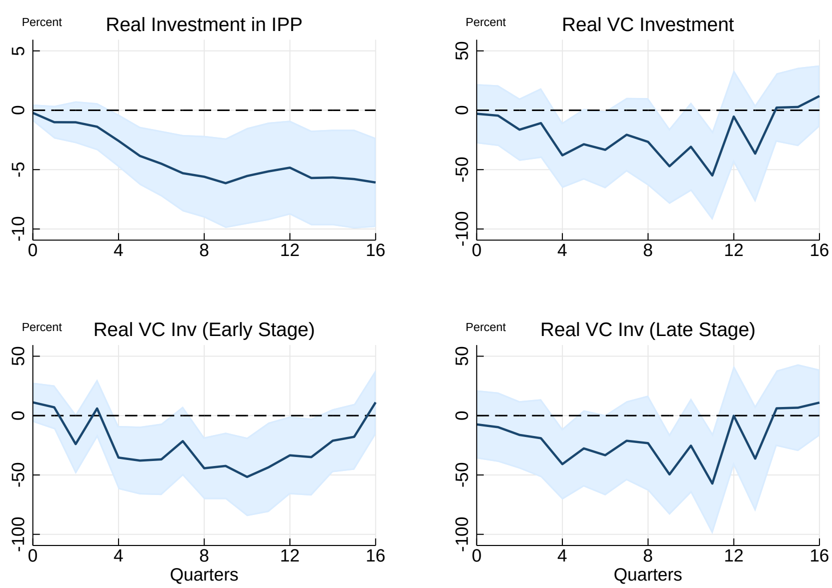
Notes: Panel A shows the impulse response of R&D spending for all firms in Compustat to a 100 basis point Romer and Romer (2004) monetary policy shock. Panel B shows the impulse response of large and small firms and firms in less and more cyclical industries. We estimate Jordà (2005) local projections $x_{i,t+h} = \alpha_i + \beta mps_t + \gamma z_t + \epsilon_{i,t}$, and plot the regression coefficient β on the monetary policy shock (the solid line). The outcome variable $x_{i,t+h}$ is log real R&D spending of firm i in quarter $t+h$. The control variables z_t include 4 lags of the outcome variable, 4 lags of the monetary policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, the excess bond premium (Gilchrist and Zakrajšek, 2012). Firm fixed effects are included. Standard errors are Driscoll and Kraay (1998) with a bandwidth of 20. The shaded area represents the 90% confidence interval.

Figure A2. Impulse Response using Aruoba and Drechsel (2023) Monetary Policy Shock

Panel A: Standard Outcome Variables



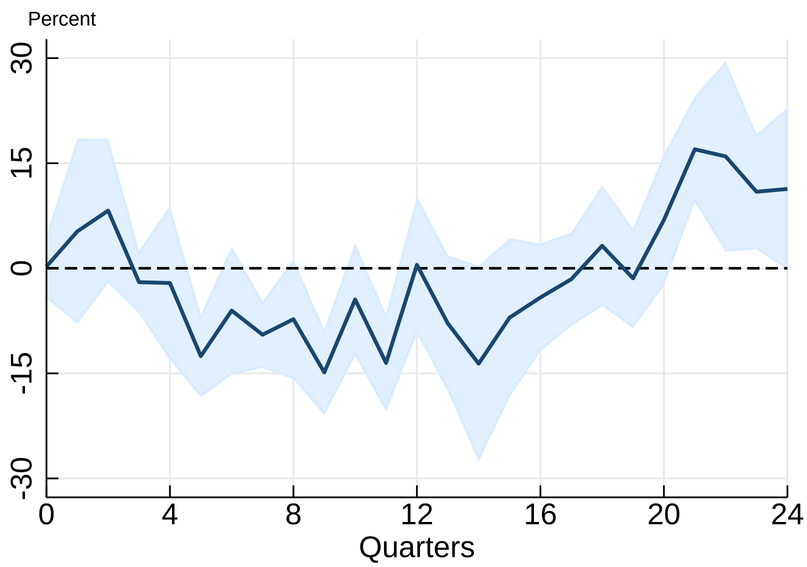
Panel B: Innovation Spending



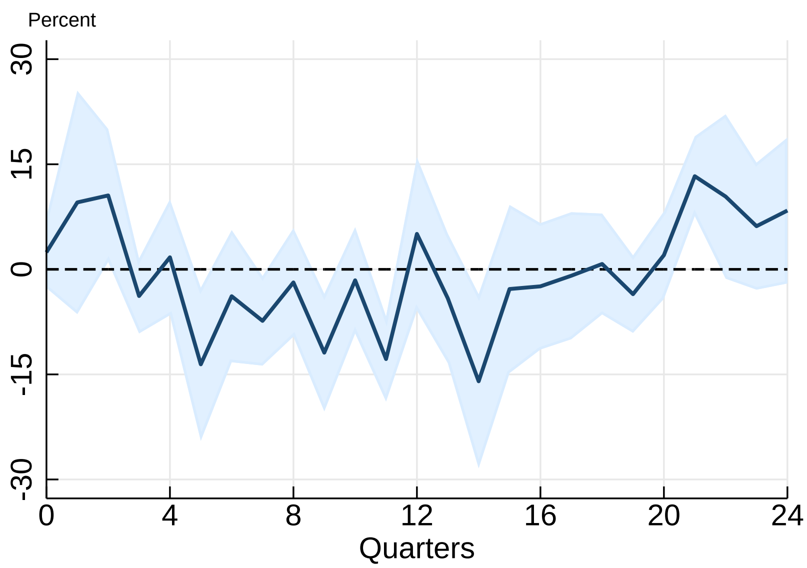
Notes: Panel A shows the impulse response of standard outcome variables, including quarterly Federal Funds rates, log real GDP, unemployment, and log real physical asset investment from the national accounts, to a 100 basis point monetary policy shock from Aruoba and Drechsel (2023). Panel B shows the impulse response of innovation spending measures, including quarterly log real investment in Intellectual Property Products (IPP) from the national accounts, as well as log real total, early stage, and late stage venture capital (VC) investment. The specification is the same as the impulse response in Figure 1. Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021). The shaded area represents the 90% confidence interval.

Figure A3. Impulse Response of Patenting to Aruoba and Drechsel (2023) Monetary Policy Shock

Panel A: Important Technologies

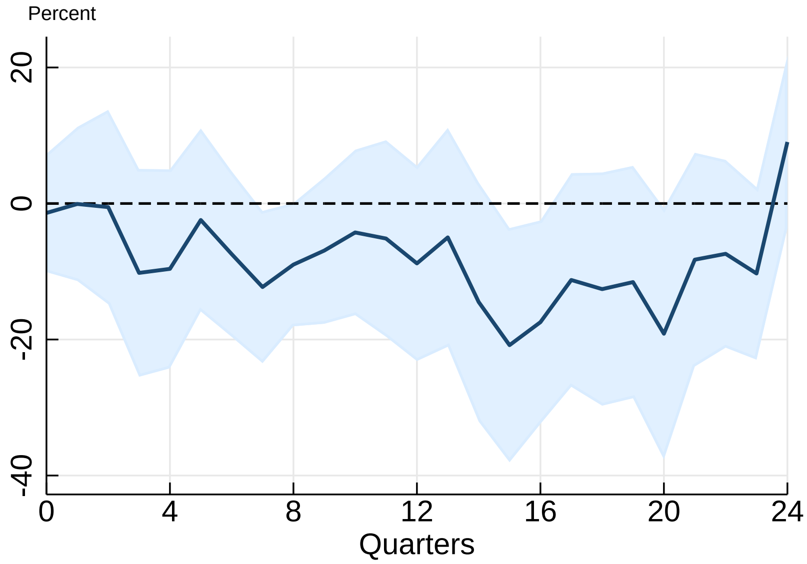


Panel B: Other Technologies



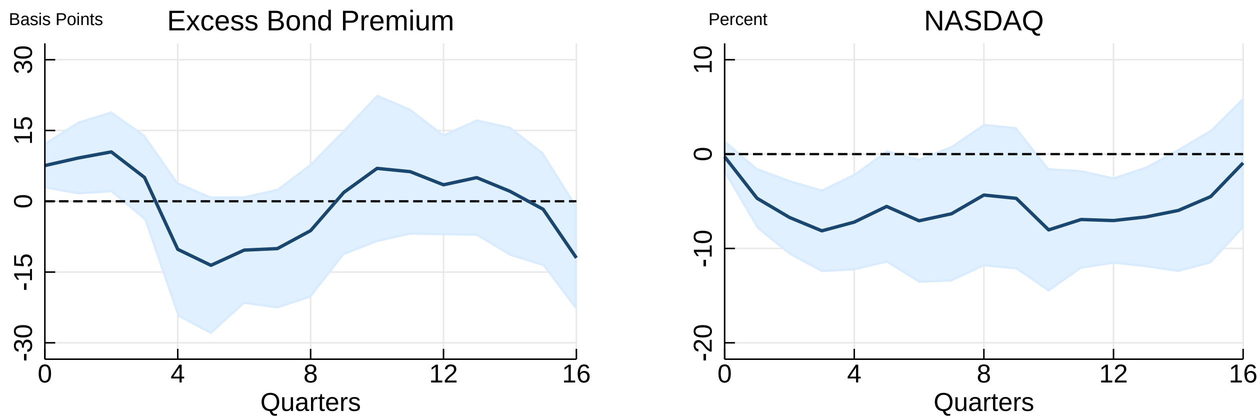
Notes: Panel A shows the impulse response of patent filings associated with the important technologies to a 100 basis point monetary policy shock from Aruoba and Drechsel (2023). Panel B shows the impulse response of patent filings associated with other technologies. The specification is the same as the impulse response in Figure 2. Standard errors are Driscoll and Kraay (1998) with a bandwidth of 20. The shaded area represents the 90% confidence interval.

Figure A4. Impulse Response of Innovation Index to Aruoba and Drechsel (2023) Monetary Policy Shock



Notes: This figure shows the impulse response of the aggregate innovation index constructed by Kogan et al. (2017) to a 100 basis point monetary policy shock from Aruoba and Drechsel (2023). The specification is the same as the impulse response in Figure 4. Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021). The shaded area represents the 90% confidence interval.

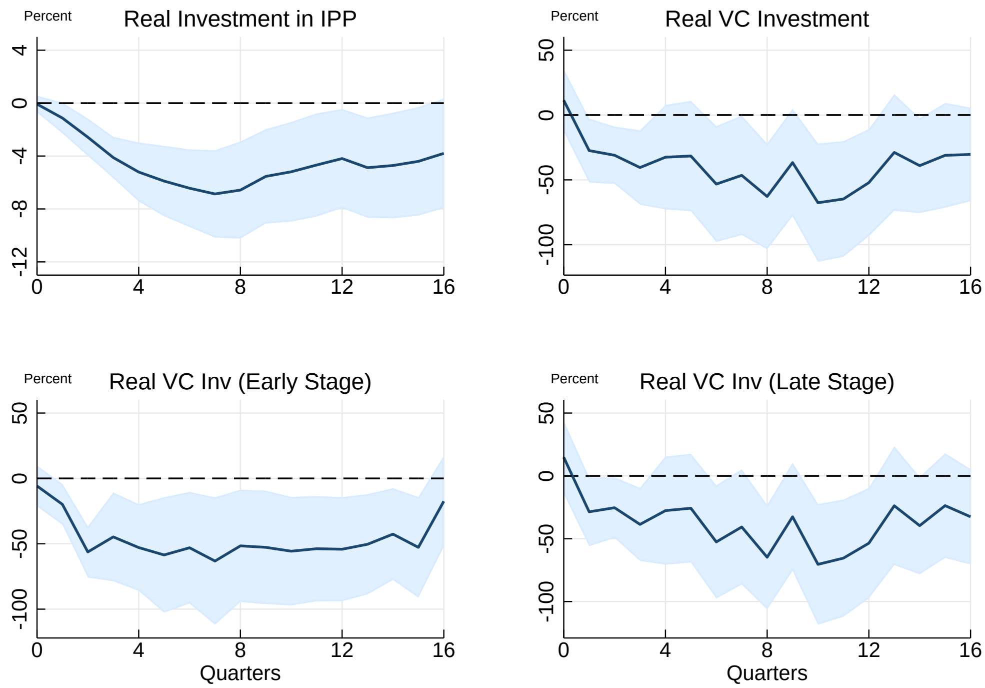
Figure A5. Impulse Response of Asset Prices to Monetary Policy Shock



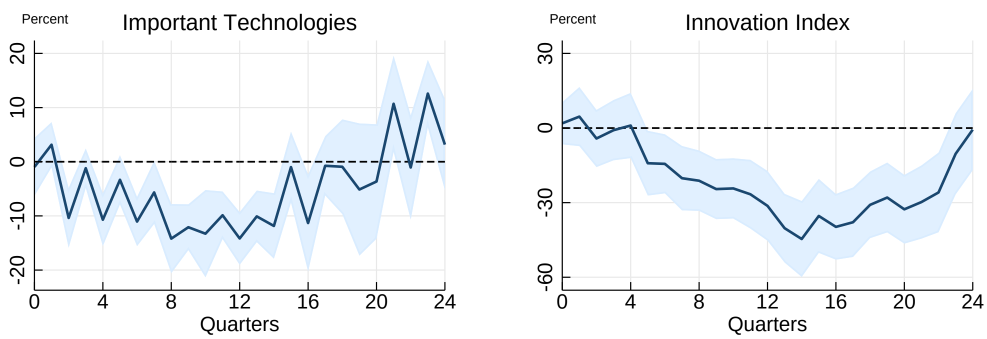
Notes: This figure shows the impulse response of the excess bond premium and the NASDAQ index to a 100 basis point Romer and Romer (2004) monetary policy shock. We estimate Jordà (2005) local projections $x_{t+h} = \alpha + \beta mps_t + \gamma z_t + \epsilon_t$, and plot the regression coefficient β on the monetary policy shock (the solid line). The control variables z_t include 4 lags of the outcome variable, 4 lags of the monetary policy shock, and 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, and the excess bond premium (Gilchrist and Zakrajšek, 2012). Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021). The shaded area represents the 90% confidence interval.

Figure A6. Impulse Response of Innovation Activities to Excess Bond Premium

Panel A: Innovation Spending



Panel B: Patent Diffusion and Innovation Index



Notes: Panel A shows the impulse response of innovation spending measures, including quarterly log real investment in Intellectual Property Products (IPP) from national accounts, as well as log real total, early stage, and late stage venture capital (VC) investment, to a 100 basis point increase in the excess bond premium (Gilchrist and Zakrajšek, 2012). Panel B shows the impulse response of patent filings associated with the important technologies and the aggregate innovation index (Kogan et al., 2017). The control variables include 4 lags of the outcome variable, 4 lags of the Fed Funds rate, log real GDP, log CPI, unemployment rate, and the excess bond premium (Gilchrist and Zakrajšek, 2012). Standard errors are Eicker–Huber–White following Montiel Olea and Plagborg-Møller (2021), except the panel regression on important technologies uses Driscoll and Kraay (1998) standard errors with a bandwidth of 20. The shaded area represents the 90% confidence interval.