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Liquidity Premium, Credit Costs, and Optimal Monetary Policy*

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Abstract

I study how monetary policy affects firms' external financing decisions. More precisely, I study the transmission mechanism of monetary policy to credit costs in a general equilibrium macroeconomic model where firms issue corporate bonds or obtain bank loans, and corporate bonds are not just stores of value but also serve a liquidity role. The model shows that an increase in the nominal policy rate can lower the borrowing cost in the corporate bond market, while increasing that in the bank loan market, and I provide empirical evidence that supports this result. The model also predicts that a higher nominal policy rate induces firms to substitute corporate bonds for bank loans, which is supported by the existing empirical evidence. In the model, the Friedman rule is suboptimal so that keeping the cost of holding liquidity at a positive level is socially optimal. The optimal policy rate is an increasing function of the degree of corporate bond liquidity.

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1 Introduction

Central banks influence firms' investment through controlling the nominal policy rate, which then gets transmitted to the real rates at which firms borrow. I study this transmission mechanism in a general equilibrium macroeconomic model where firms have two options for external financing: they can issue corporate bonds or obtain bank loans. A theoretical novelty of my model is that corporate bonds are not just stores of value but also serve a liquidity role. The model delivers three predictions. First, an increase in the nominal policy rate can lower the borrowing cost in the corporate bond market, while increasing that in the bank loan market. This is in contrast with the common belief that all rates in the economy move in the same direction in response to changes in monetary policy.[1] I provide empirical evidence that supports the result. Second, a higher nominal policy rate induces firms to substitute corporate bonds for bank loans, and this result is supported by the existing empirical evidence. Third, the Friedman rule is suboptimal so that keeping the cost of holding liquidity at a positive level is socially optimal. The optimal policy rate is an increasing function of the degree of corporate bond liquidity.

To provide a concrete concept of liquidity of corporate bonds, I employ a model in the tradition of monetary-search theory, extended to include firms externally financing their production. Consumers and firms trade in a decentralized market, where trade is bilateral, credit is imperfect, and thus a medium of exchange is necessary. Agents allocate their wealth between money and corporate bonds. Both can serve liquidity purposes, but only a fraction of corporate bond holdings can be used towards trades. This assumption is meant to capture the idea that, when in need of extra money, agents liquidate corporate bonds in a secondary market, but due to frictions, trading delays, intermediation fees, etc., only a fraction of these bonds can be sold. Hence, the fraction of bonds the agents can use is meant to capture the degree of liquidity in the secondary market for those assets. Firms need to raise funds to finance production, and they can do so whether by issuing corporate bonds or by obtaining

[1] Consider the following quote from Jones (2017)'s Macroeconomics textbook: "The Federal Reserve sets ... the federal funds rate, ... effectively setting the rate[s] at which [firms] borrow ... in financial *markets* [emphasis added]." This quote implies that the Federal Reserve implements monetary policy changes by targeting a single nominal rate but anticipates that these changes will be transmitted (symmetrically) to the rates in all financial markets.

a bank loan. Naturally, the liquidity properties of corporate bonds affect their equilibrium price and, consequently, the issuance decision of firms.

Incorporating liquidity is the key to obtaining the main result of the paper. Thus, it is important to justify that this choice is empirically relevant. I highlight the fact that the U.S. corporate bond secondary market underwent a structural change during the early 2000s with the introduction of the Transaction Reporting and Compliance Engine (TRACE) that mandated reporting transaction-related information in all over-the-counter (OTC) transactions. Empirical evidence shows that the corporate bond secondary market liquidity has improved substantially as a result of the increased transparency under the new system, and that liquidity has become a significant component of the corporate bond premium since the TRACE was implemented.[2]

In the model, the nominal policy rate affects the cost of issuing corporate bonds and borrowing from a bank as follows. A higher nominal policy rate increases the opportunity cost of holding money, reduces real money balances, increases the liquidity premium of corporate bonds, and makes issuing corporate bonds less expensive. This pass-through becomes stronger when the corporate bond secondary market is more liquid. The real loan rates are determined in the OTC market for loans where firms and banks are matched and bargain over the size and the interest rate of a loan. With an increase in the nominal policy rate, the cost of holding money increases, agents carry less liquidity, and firms borrow less from a bank since agents can afford less. As a result, the real loan rate increases because it depends positively on the marginal benefit of a loan, and the latter decreases in the loan size.

To empirically identify the channel through which the nominal policy rate affects the liquidity premium of corporate bonds (which I label the liquidity premium channel of monetary policy transmission), I use the fact that the introduction of the TRACE brought a structural change in the liquidity of the corporate bond secondary market. The liquidity

[2]Two observations are in order. First, Bessembinder, Maxwell, and Venkataraman (2006), Edwards, Harris, and Piwowar (2007), and Goldstein, Hotchkiss, and Sirri (2007) find that the secondary market liquidity increased by 50–84% with the mandatory transaction reporting system. Second, Bao, Pan, and Wang (2011) find that liquidity explains 47% to 60% of the time variation of aggregate bond spreads of high-rated bonds, even larger than the variation that can be explained by credit risk. Also, He and Milbradt (2014) find that liquidity accounts for 44% of credit spreads for investment-grade corporate bonds and 31% for speculative-grade corporate bonds.

premium channel is identified by the difference in the effect of an increase in the nominal policy rate on the corporate bond premium between the pre- and the post-TRACE periods. I employ the structural vector autoregression (SVAR) and the local projection approaches. To ensure the results are not driven by other macro factors and to limit any potential reverse causality issues, I exploit the high-frequency identified surprises from Federal Funds futures around the Federal Open Market Committee policy announcements as an external instrument, following Gertler and Karadi (2015).

The empirical analysis shows that the liquidity premium of corporate bonds indeed responds negatively to an increase in the nominal policy rate as the model predicts. Direct liquidity measures such as bid-ask spreads and trading volume further confirm the result. In the pre-TRACE period when the secondary market liquidity is low, a higher nominal policy rate still increases the bond premium, which is consistent with Gertler and Karadi (2015). However, surprisingly, in the post-TRACE period when the secondary market is highly liquid, the liquidity premium channel turns out to be so strong that a higher nominal policy rate decreases the bond premium. On the contrary, the real loan rates increase in the nominal policy rate.

Another interesting prediction of the model is that an increase in the nominal policy rate induces firms to substitute corporate bonds for bank loans. When firms have the option of financing both through issuing corporate bonds and borrowing from a bank, firms with large corporate bond issuance rely less on bank loans and thus can negotiate for a lower real loan rate. A higher nominal policy rate makes issuing corporate bonds less expensive, allowing firms to issue more corporate bonds for the strategic purpose of lowering their financing costs. Becker and Ivashina (2014) provide direct empirical support for this theoretical finding.

Lastly, I use the model to study optimal monetary policy for the period, such as the post-TRACE period, when the liquidity premium channel of monetary policy transmission is dominant in the response of the bond premium to the nominal policy rate. A common result in monetary theory is that an increase in the nominal policy rate hurts welfare: a higher nominal policy rate increases the opportunity cost of holding liquidity, induces agents to carry less liquidity, and reduces the quantity of goods they can afford. In my model, however, the Friedman rule—implementing zero nominal policy rate—is suboptimal.[3] The intuition behind the suboptimality of the Friedman rule is as follows. Assume that the nominal policy rate is currently low, so that the borrowing cost in the corporate bond market is high, while that in the bank loan market is low. When meeting a firm for trade, agents face risk: they can meet a firm that obtained a loan from a bank and have large production capacity, or a firm that financed only by issuing corporate bonds and have small production capacity. Increasing the nominal policy rate makes issuing corporate bonds cheaper and borrowing from a bank more expensive, thereby reducing the risk agents face and increasing welfare. The optimal nominal policy rate depends on the corporate bond secondary market liquidity and the distribution of firms along their ways of financing. The more liquid the corporate bond secondary market, or the more firms financing through issuing corporate bonds, the higher the optimal policy rate.

Related literature. A collection of empirical papers uses monetary policy as a source of aggregate variation and studies its effect on the firm-side of the economy. One strand of such literature examines firms' heterogeneous responses in their investment, interpreting the results as an indication of the presence of financial frictions. The heterogeneity depends on the firms' various characteristics such as cash flows (Oliner and Rudebusch (1992)), size (Gertler and Gilchrist (1994), Bernanke, Gertler, and Gilchrist (1996)), liquid asset holdings (Kashyap, Lamont, and Stein (1994), Jeenas (2019)), default risk (Ottonello and Winberry (2020)), and age/dividend payouts (Cloyne, Ferreira, Froemel, and Surico (2019)). This paper contributes to the literature by studying the heterogeneity in the responses of different financial markets for firms' external financing, including the corporate bond and the bank loan markets, which implies that firms will respond differently depending on their access to markets.

Another related empirical literature is the one that examines the relationship between monetary policy and the liquidity premium of liquid assets. Nagel (2016) and Drechsler,

[3] A negative relationship between the nominal policy rate and welfare characterizes a large class of monetary models, including Lagos and Wright (2005) and the majority of models that build upon their framework. However, there are exceptions to this rule, especially models with search externality. Later, when I review the related literature, I provide a more detailed discussion of exceptions to this result, and I claim that the channel through which my model can deliver a positive relationship between the nominal policy rate and welfare has not been highlighted before.

Savov, and Schnabl (2018) provide empirical evidence that the liquidity premium of Treasuries is positively associated with the short-term interest rates. The rationale behind it is the exact same as the one considered in this paper: the short-term interest rates imply a higher opportunity cost of holding money and hence a higher premium for the liquidity service benefits of assets that can be substitutes for money. This paper complements the literature by providing evidence that a similar relationship between monetary policy and the liquidity premium holds also for corporate bonds.[4]

This paper also contributes to the empirical literature that investigates the effect of the introduction of the TRACE to the corporate bond secondary market. A series of papers, such as Bessembinder, Maxwell, and Venkataraman (2006), Edwards, Harris, and Piwowar (2007), Goldstein, Hotchkiss, and Sirri (2007), and Asquith, Covert, and Pathak (2013), study the impact of the mandatory transaction reporting through the TRACE on the trading costs and the liquidity of the corporate bond secondary market. This paper contributes to the literature by looking at the impact of the introduction of the TRACE on the response of the corporate bond market to monetary policy.

Also related is the literature that studies firms' financing choices and the composition of credit, which includes for instance Denis and Mihov (2003), Adrian, Colla, and Shin (2012), Becker and Ivashina (2014), and Schwert (2018). This paper is especially relevant to Becker and Ivashina (2014). One of the theoretical findings of this paper is that firms switch from loans to bonds following an increase in the nominal policy rate. Becker and Ivashina (2014) provide direct empirical support for this finding.

The model in this paper builds on the New Monetarist framework, recent advances in monetary economics, as surveyed in Lagos, Rocheteau, and Wright (2017) and Nosal and Rocheteau (2017). The consumer-side of the model is based on Lagos and Wright (2005). In the model, corporate bonds have a liquidity premium due to the liquidity service they provide, and the monetary policy affects the costs of holding money and in turn the price of corporate bonds through their liquidity premium, following Geromichalos, Licari, and Suárez-Lledó (2007), Lagos (2011), Nosal and Rocheteau (2012), Andolfatto, Berentsen, and

[4] Lagos and Zhang (2020) provide an empirical study on the equity market.

Waller (2013), and Hu and Rocheteau (2015).[5]

Another paper that studies how monetary policy affects corporate finance is Rocheteau, Wright, and Zhang (2018). While in their paper firms finance investment by internal financing or bank loans, the firm-side of the model in this paper focuses solely on external financing, in particular corporate bond issues and bank loans.[6] In addition, this paper integrates the consumer- and the firm-sides and studies how they interact with each other. By doing so, the supply of corporate bonds becomes endogenous, instead of being supplied at an exogenous level. Geromichalos and Herrenbrueck (2016b) also endogenize the supply of assets, but in their model asset issuers and sellers who produce consumption goods are different agents. On the other hand, in this paper firms issue bonds to finance their production.

As for the suboptimality of the Friedman rule, there exist generally two classes of models where positive costs of holding money can be welfare improving.[7] One is the models where inflation has distributive effects (see for example Molico (2006) and Rocheteau, Weill, and Wong (2019)). The other is the models with free entry to search (see for example Rocheteau and Wright (2005) and Berentsen, Rocheteau, and Shi (2007)). When there is search externality, the Friedman rule is optimal if and only if the Hosios (1990) condition is satisfied. When the Hosios (1990) condition does not hold, a deviation from the Friedman rule can be optimal since it can adjust the inefficiently large or small number of agents who are in search. This paper provides a new rationale for why the Friedman rule can be suboptimal, which is due to the heterogeneity in the effect of monetary policy across different financing sources.

Definitions of premiums. This paper defines the liquidity premium and the bond premium as follows. The liquidity premium is a price premium that investors are willing to pay for the liquidity service that assets provide. It is defined as the price of an asset minus the price

[5] While in this paper the liquidity property of assets is direct in the sense that they serve as a medium of exchange or collateral and thus help to facilitate trade in frictional decentralized markets for goods, it can be microfounded by introducing secondary markets where agents can liquidate assets for money or by using information theory. See Berentsen, Huber, and Marchesiani (2014, 2016), Han (2015), Geromichalos and Herrenbrueck (2016a, 2016b, 2017), Geromichalos, Herrenbrueck, and Salyer (2016), Mattesini and Nosal (2016), Herrenbrueck and Geromichalos (2017), Herrenbrueck (2019a), and Madison (2019) for the examples for the former, and Rocheteau, Wright, and Xiao (2018) for the latter.

[6] The OTC market for bank loans in this paper follows Rocheteau, Wright, and Zhang (2018).

[7] For an exhaustive list of the papers in which a deviation from the Friedman rule can be optimal, see Section 6.9 of Nosal and Rocheteau (2017).

if the asset did not provide any liquidity service. This definition follows the New Monetarist literature (see Lagos, Rocheteau, and Wright (2017) and Nosal and Rocheteau (2017) for surveys). The liquidity premium defined in this way moves in the same direction as that in Nagel (2016) and Drechsler, Savov, and Schnabl (2018), who define the liquidity premium in yield, as the yield if an asset did not provide any liquidity service minus the yield of the asset. The definition of the bond premium follows Gilchrist and Zakrajšek (2012), who defines the bond premium as the yield of a bond minus the yield associated with a price that equals the net present value of the cash flows, or the fundamental value, of the bond. Under these definitions, the liquidity premium and the bond premium are negatively correlated.

Structure of the paper. Section 2 presents the environment of the model. Section 3 characterizes the equilibrium of the model and examines the transmission mechanism of monetary policy to credit costs. Section 4 provides empirical analysis and evidence that supports such mechanism. Section 5 analyzes how monetary policy affects the composition of firms' credit. Section 6 studies optimal monetary policy. Section 7 concludes. The online appendices contain a theory appendix and an appendix that explains data sources and includes additional figures for robustness checks.

2 The Model

The model builds on Lagos and Wright (2005) and introduces firms externally financing their production. Time is discrete and continues forever. Each period is divided into two subperiods. In the first subperiod, there is a decentralized market (DM) where a specialized good is traded. In the second subperiod, three markets open in order: a frictionless centralized market (CM) where agents settle liabilities and trade a consumption good and assets; an over-the-counter (OTC) market for bank loans, as in Rocheteau, Wright, and Zhang (2018); and a competitive market for intermediate goods. The consumption good in the CM is taken as the numeraire.

There are four agents: firms, intermediate good suppliers, banks, and consumers. Firms produce special goods (hereafter, DM goods) in the DM and sell them to consumers. To produce the DM goods, they need to purchase intermediate goods from the intermediate good suppliers, and, to do so, they need to externally finance. The intermediate good suppliers (hereafter, suppliers) can produce intermediate goods and provide them to firms. Bank loans are one of the ways of external financing, and banks do loan services for firms. Consumers buy the DM goods from firms in the DM and consume them. The measure of firms and consumers is 1. The measure of banks is the same as that of firms borrowing from a bank. The measure of suppliers is irrelevant due to constant returns to scale (CRS) in their production.

Agents live forever, except for firms that live one period. Firms are born in the second subperiod and die next period in the second subperiod after settlement. Agents discount across periods, but not subperiods, at rate $\beta \in (0, 1)$. All agents have a linear preference over the numeraire, c, where $c > 0$ is interpreted as consumption of the numeraire and $c < 0$ as production. Additionally, consumers, who consume the DM goods in the first subperiod in the DM, derive utility, $u(q)$, where q is the consumption of the DM goods. u is twice continuously differentiable, $u(0) = 0$, $u'(0) = \infty$, $u'(\infty) = 0$, $u' > 0$ and $u'' < 0$. Firms can transform intermediate goods acquired from suppliers into the DM goods with linear technology.[8] Suppliers can produce intermediate goods at unit cost.

Firms, born in the second subperiod, are in need of intermediate goods to produce the DM goods in the following first subperiod. When purchasing intermediate goods from suppliers, firms need to pay in numeraire, and firms that are just born are assumed not to be able to produce numeraire goods. Firms can acquire numeraire goods either by obtaining a loan from a bank or by issuing one-period real corporate bonds that yield a unit of numeraire in the next second subperiod. For the moment, it is assumed that the measure $1 - \lambda \in (0, 1)$ of firms finance by borrowing from a bank, while the measure λ of firms finance by issuing corporate bonds.[9] The issuance decision of firms endogenously determines the supply of corporate bonds. On the demand side of the corporate bond market are consumers. Banks are not allowed to hold corporate bonds.

[8]This is without loss of generality, and all go through with a concave production function. Assume that, with k amount of intermediate goods, firms can produce $f(k)$ amount of the DM goods, where f is twice continuously differentiable, $f(0) = 0$, $f'(0) = \infty$, $f'(\infty) = 0$, $f' > 0$ and $f'' < 0$. This in turn means that, to produce q amount of the DM goods, a firm needs $f^{-1}(q)$ amount of intermediate goods. f^{-1} is effectively a convex cost function, and all remaining analysis is the same.

[9]Section 5 endogenizes the ways of firms' financing.

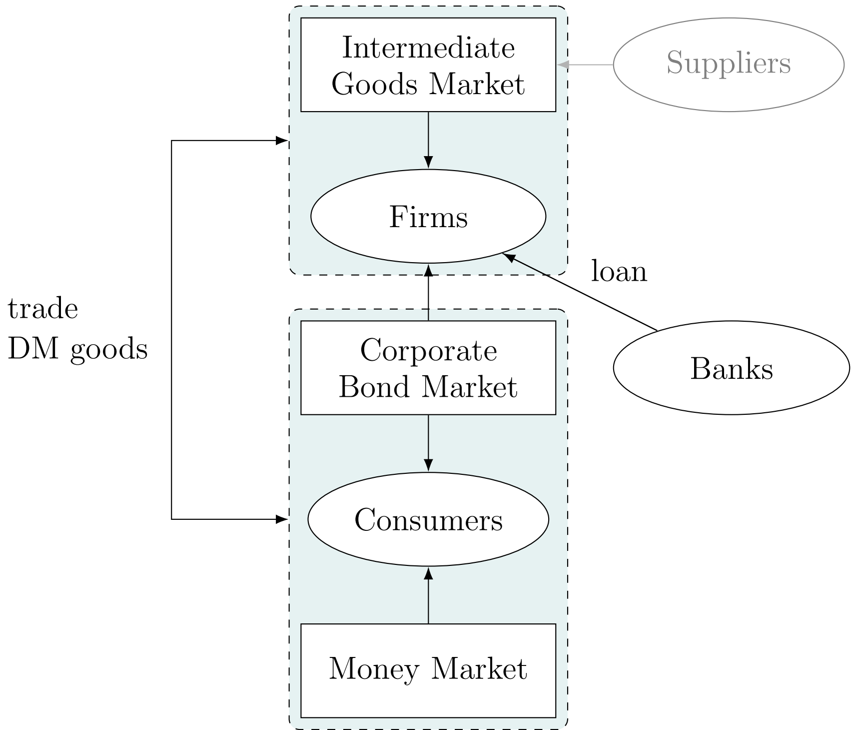

Figure 1. The environment of the model

The other asset traded in the CM, besides corporate bonds, is money. Monetary authority controls the money supply, and the supply evolves according to $M_{t+1} = (1+\pi)M_t$, where π is the rate of monetary expansion (or contraction if $\pi < 0$) implemented by lump-sum transfers to (or taxes on) consumers at the beginning of the second subperiod. In a stationary equilibrium, π is also the inflation rate. $i \equiv (1+\pi)/\beta - 1$ represents the cost of holding money and, it is the nominal interest rate on an illiquid bond (if such bond were introduced). An equilibrium exists for $i > 0$, or $\pi > \beta - 1$, and the Friedman rule is considered as $i \to 0$, or $\pi \to \beta - 1$.

In the DM, firms produce the DM goods using intermediate goods and sell them to consumers. Trade in the DM is bilateral and agents are anonymous and lack commitment. Thus, trade has to be quid pro quo and necessitates a medium of exchange. Both money and corporate bonds can play this role. But corporate bonds are partially liquid, and only a fraction $\chi \in (0, 1]$ can be used as payment. Consumers meet firms randomly and negotiate over the terms of trade. All consumers match with a firm. The surplus generated within a match is split according to Kalai's proportional bargaining solution, and the consumer's bargaining power is $\theta \in (0,1)$. In the OTC market for loans, all firms match with a bank. Terms of a loan contract are determined through generalized Nash bargaining between a firm and a bank, and the banks' bargaining power is $\eta \in (0,1)$.

The environment of the model is summarized in Figure 1.

3 Analysis of the Model

3.1 Value Functions

Consider a consumer in the second subperiod who carries to the CM financial wealth w denominated in numeraire and chooses a portfolio of real balances (units of money in terms of numeraire) and corporate bonds to bring to the DM. The value function of the consumer in the CM is

$$W^C(w) = \max_{c,\hat{m}\geq 0,\hat{a}\geq 0} c + \beta V^C(\hat{m},\hat{a}) \quad \text{s.t.} \quad c + (1+\pi)\hat{m} + \psi\hat{a} = w + T, \tag{1}$$

where W^C and V^C are the value functions of a consumer in the second and the first subperiods, respectively, c is consumption (or production if $c < 0$) of numeraire goods, $\hat{m}$ is real balances (units of money in terms of numeraire), $\hat{a}$ is the amount of corporate bonds purchased, ψ is the price of corporate bonds, and T is the lump-sum transfer in terms of numeraire (or taxes if $T < 0$). Since the rate of return on money is $1/(1+\pi)$, a consumer accumulates $(1+\pi)\hat{m}$ of real balances this period to hold $\hat{m}$ at the start of the next period. Eliminating c using the constraint, the value function reduces to

$$W^C(w) = w + T + \max_{\hat{m}\geq 0,\hat{a}\geq 0} \{-(1+\pi)\hat{m} - \psi\hat{a} + \beta V^C(\hat{m},\hat{a})\}, \tag{2}$$

which shows that W^C is linear in w and that the choice of $(\hat{m},\hat{a})$ is independent of w. In the following first subperiod, the consumer randomly matches with a firm and trades the DM goods. In the DM, the consumer bargains with a firm over how many DM goods to purchase from the firm, q, and how much financial wealth to transfer to the firm in return for the DM goods, p. With probability $1-\lambda$, the consumer will match with a firm that finances through borrowing from a bank, and the terms of trade with such firm are denoted by (q_L, p_L). With probability λ, the consumer will match with a firm that finances through issuing corporate bonds, and the terms of trade with such firm are denoted by (q_B, p_B). When purchasing q amount of the DM goods, the consumer derives $u(q)$ of utility from consuming them. After paying p amount of financial wealth to a firm in exchange for the DM goods purchased, the consumer brings $\hat{m}+\hat{a}-p$ amount of leftover financial wealth to the CM. The value function of a consumer who brings $\hat{m}$ amount of real balances and $\hat{a}$ amount of corporate bonds to the DM is

$$V^C(\hat{m}, \hat{a}) = (1-\lambda)\left[u(q_L) + W^C(\hat{m}+\hat{a}-p_L)\right] + \lambda\left[u(q_B) + W^C(\hat{m}+\hat{a}-p_B)\right], \quad (3)$$

which, using the linearity of W^C, reduces to

$$V^C(\hat{m}, \hat{a}) = (1-\lambda)\left[u(q_L) - p_L\right] + \lambda\left[u(q_B) - p_B\right] + W^C(\hat{m}+\hat{a}). \quad (4)$$

Next consider the value function of an intermediate good supplier in the second subperiod:

$$W^S = \max_{c,k\geq 0} c + \beta W^S \quad \text{s.t.} \quad c + k = p_k k, \quad (5)$$

where k is the amount of intermediate goods produced and p_k is their price. Suppliers do not trade in the DM and do not carry any money or corporate bonds due to the cost of holding money and because corporate bonds will be priced at the liquidity premium. In the competitive market for intermediate goods that comes after the CM, suppliers choose the amount of intermediate goods, k, to produce at a linear cost taking its price, p_k, as given. A supplier finds k that maximizes $-k+p_k k$. If the intermediate goods market is active, $p_k = 1$.

In the OTC market for loans, a bank provides a loan to a firm. The terms of a loan contract, denoted by (k, r_ℓ), are determined through bargaining between a firm and a bank: a firm borrows k amount of numeraire from a bank and pays back $(1+r_\ell)k$ amount of numeraire in the next second subperiod. The value function of a bank in the CM with financial wealth w denominated in numeraire and a loan contract (k, r_ℓ) is

$$W^B(w) = \max_c c + \beta W^B((1+r_\ell)k) \quad \text{s.t.} \quad c + k = w. \tag{6}$$

The constraint can be written as $k = w - c$, and this represents the balance sheet of the bank. It indicates that the amount of a loan given to a firm, k, is covered by the financial wealth of the bank, $w - c$, which can be thought of as bank capital. Eliminating c using the constraint, the value function reduces to $W^B(w) = w - k + \beta W^B((1+r_\ell)k)$.

Now consider a firm in the second subperiod that is just born and finances through borrowing from a bank under the terms of a loan contract (k, r_ℓ). With k amount of numeraire borrowed from a bank, the firm purchases k amount of intermediate goods from suppliers at price $p_k = 1$. In the following first subperiod, the firm matches with a consumer and trade the DM goods, and the terms of trade are denoted by (q_L, p_L). After trading in the DM, the firm brings $k - q_L$ of leftover intermediate goods and p_L of financial wealth to the CM and needs to pay back $(1+r_\ell)k$ units of numeraire to the bank. The value function in the first subperiod of a firm with a loan contract (k, r_ℓ) is

$$V^F(k, (1+r_\ell)k) = W^F(k - q_L, p_L, (1+r_\ell)k), \tag{7}$$

where V^F and W^F are the value functions of a firm in the first and the second subperiods, respectively. The value function of a firm in the second subperiod after trading in the DM is

$$W^F(k - q_L, p_L, (1+r_\ell)k) = \max_c c \quad \text{s.t.} \quad c = k - q_L + p_L - (1+r_\ell)k, \tag{8}$$

which simply reduces to $W^F(k - q_L, p_L, (1+r_\ell)k) = k - q_L + p_L - (1+r_\ell)k$.[10]

A firm that finances through issuing corporate bonds first decides the amount of corporate bonds to issue, $\hat{A}$, taking their price ψ in the CM as given. With $\psi\hat{A}$ amount of numeraire acquired by issuing corporate bonds, the firm purchases intermediate goods from

[10] It is assumed that the firm can use the leftover intermediate goods to produce numeraire goods at unit cost, in case the firm did not use all the intermediate goods it held to produce the DM goods. Allowing a firm to be able to use the leftover intermediate goods enters as an outside option for firms in bargaining over the terms of DM trade, and this technology is not used in equilibrium. This assumption is just for simplifying the exposition.

suppliers at price $p_k = 1$. In the following first subperiod, the firm matches with a consumer and trade the DM goods, and the terms of trade are denoted by (q_B, p_B). After trading in the DM, the firm brings $\psi\hat{A} - q_B$ of leftover intermediate goods and p_B of financial wealth to the CM and needs to pay $\hat{A}$ units of numeraire to the consumers who hold the corporate bonds. The value function in the first subperiod of a firm that issued $\hat{A}$ amount of corporate bonds in the previous second subperiod at price ψ is

$$V^F(\psi\hat{A}, \hat{A}) = W^F(\psi\hat{A} - q_B, p_B, \hat{A}). \tag{9}$$

The value function of a firm in the second subperiod after trading in the DM is

$$W^F(\psi\hat{A} - q_B, p_B, \hat{A}) = \max_c c \quad \text{s.t.} \quad c = \psi\hat{A} - q_B + p_B - \hat{A}, \tag{10}$$

which simply reduces to $W^F(\psi\hat{A} - q_B, p_B, \hat{A}) = \psi\hat{A} - q_B + p_B - \hat{A}$. Using the linearity of W^F, a newborn firm in the second subperiod decides the amount of corporate bonds to issue by solving

$$\max_{\hat{A}\geq 0} \beta V^F(\psi\hat{A}, \hat{A}) = \max_{\hat{A}\geq 0} \beta\{(p_B - q_B) - (1-\psi)\hat{A}\}. \tag{11}$$

3.2 Terms of Trade

Consider a meeting in the DM between a consumer who carries m amount of real balances and a amount of corporate bonds and a firm that brings k amount of intermediate goods. The two parties bargain over the quantity of the DM goods to trade, q, and the amount of financial wealth for the consumer to transfer to the firm, p. Corporate bonds are partially liquid, and only a fraction $\chi \in (0, 1]$ can be used as a medium of exchange. Thus, the maximum amount of financial wealth that the consumer can use for trade is $m + \chi a$. The firm can produce the DM goods with a linear technology up to k. Trade is as a result subject to both the consumer's liquidity and the firm's capacity constraints: $p \leq m + \chi a$ and $q \leq k$. The total surplus generated within a meeting is split according to Kalai's proportional bargaining solution, and the consumer's bargaining power is $\theta \in (0, 1)$. The consumer's continuation value with trade is $u(q) + W^C(m + a - p)$: the consumer derives $u(q)$ of utility from consuming q amount of the DM goods and brings $m + a - p$ amount of leftover financial wealth to the CM after transferring p amount of financial wealth to the firm as a payment. The consumer's continuation value without trade is $W^C(m + a)$. Thus, the consumer's surplus is $u(q) + W^C(m + a - p) - W^C(m + a)$, which, using the linearity of W^C, reduces to $u(q) - p$. The firm's continuation value with trade is $W^F(k - q, p, \cdot)$, where the last argument is the liabilities that the firm needs to pay back in the subsequent second subperiod to either consumers (who hold the corporate bonds if the firm financed through issuing corporate bonds) or a bank (according to a loan contract if the firm financed through a bank loan). The firm brings $k - q$ amount of leftover intermediate goods after producing q amount of DM goods with a linear technology and p amount of financial wealth that it received from the consumer as a payment. The firm's continuation value without trade is $W^F(k, 0, \cdot)$. Thus, the firm's surplus is $W^F(k - q, p, \cdot) - W^F(k, 0, \cdot)$, which, using the linearity of W^F, reduces to $p - q$. The total surplus is the sum of the consumer's surplus and the firm's surplus and equals $u(q) - q$. The bargaining solution is

$$p = v(q) \equiv (1 - \theta)u(q) + \theta q, \quad v'(q) > 0, \tag{12}$$

$$q = \min\{v^{-1}(m + \chi a), k\}. \tag{13}$$

The consumer must transfer $p = v(q)$ amount of financial wealth to the firm to get q amount of the DM goods, and a larger amount of financial wealth needs to be transferred to purchase a larger amount of the DM goods. p solves $u(q) - p = \theta(u(q) - q)$ or $p - q = (1 - \theta)(u(q) - q)$ so that the consumer's surplus, $u(q) - p$, becomes θ share of the total surplus, $u(q) - q$, and that the firm's surplus, $p - q$, becomes $1 - \theta$ share of the total surplus. The first best solution to the bargaining problem that maximizes the total surplus is denoted by (p^*, q^*), where $p^* = v(q^*)$ and q^* satisfies $u'(q^*) = 1$. With $m + \chi a$ amount of financial wealth that can be used for trade, the consumer can buy up to $v^{-1}(m + \chi a)$ amount of the DM goods. With k amount of intermediate goods in hand, the firm can produce up to k amount of the DM goods. In equilibrium, $m + \chi a \leq v(q^*)$ and $k \leq q^*$ hold: the consumer will not want to bring more financial wealth than she needs to buy q^* amount of the DM goods, and the firm will not want to bring more intermediate goods than it needs to produce q^* amount of the DM goods. Observing that the total surplus $u(q) - q$ increases in q until $q = q^*$, the shorter side between the consumer's liquidity position and the firm's capacity determines the bargaining solution. Thus, q is given by the minimum between $v^{-1}(m + \chi a)$ and k.

3.3 Loan Contract

Consider a meeting in the OTC market for loans in the second subperiod between a bank with w amount of bank capital that can be lent as a loan and a firm that finances through borrowing from a bank. The two parties bargain over the amount of numeraire that the bank lends to the firm, k, and the amount of numeraire that the firm needs to repay to the bank in the next second subperiod, $(1 + r_\ell)k$, where r_ℓ is the real lending rate. Terms of a loan contract are determined through generalized Nash bargaining between the firm and the bank, and the bank's bargaining power is $\eta \in (0, 1)$. The firm's continuation value with a loan contract (k, r_ℓ) is $\beta V^F(k, (1 + r_\ell)k)$, and the firm's continuation value without a loan contract is $\beta V^F(0, 0)$. Thus, the firm's surplus is $\beta[V^F(k, (1+r_\ell)k) - V^F(0, 0)]$, which, using (7) and the linearity of W^F, reduces to $\beta[p_L - q_L - r_\ell k]$. Using (12) and (13), it further reduces to $\beta[(1 - \theta)(u(q_L) - q_L) - r_\ell k]$, where $q_L = \min\{v^{-1}(\tilde{m} + \chi\tilde{a}), k\}$ when the firm believes that a consumer will carry $\tilde{m}$ amount of real balances and $\tilde{a}$ amount of corporate bonds to the DM. The bank's continuation value with a loan contract (k, r_ℓ) is $\beta W^B((1 + r_\ell)k + w - k)$, and the bank's continuation value without a loan contract is $\beta W^B(w)$. Thus, the bank's surplus is $\beta[W^B((1 + r_\ell)k + w - k) - W^B(w)]$, which, using the linearity of W^B, reduces to $\beta r_\ell k$.[11] The terms of a loan contract specify (k, r_ℓ) that solves

$$\max_{k,r_\ell} \left((1 - \theta)(u(\min\{v^{-1}(\tilde{m} + \chi\tilde{a}), k\}) - \min\{v^{-1}(\tilde{m} + \chi\tilde{a}), k\}) - r_\ell k\right)^{1-\eta} \left(r_\ell k\right)^\eta. \tag{14}$$

[11] It is assumed that a bank can use its bank capital (which is in numeraire) that was not lent in the following way. Assume that a bank lent only $k < w$ amount to a firm and has $w - k$ amount of leftover numeraire in hand. It will then go to the intermediate goods market, exchange the leftover nuemraire with intermediate goods, and, in the next period CM, produce numeraire goods using the intermediate goods at unit cost. I assumed that banks have access to this technology. This technology is not used on the equilibrium path, and it is just for simplifying the exposition.

Since the firm will not want to borrow more than it needs to produce the amount of the DM goods that a consumer can afford, $v^{-1}(\tilde{m} + \chi\tilde{a})$, the bargaining problem simplifies to

$$\max_{k \le v^{-1}(\tilde{m}+\chi\tilde{a}), r_\ell} \left((1-\theta)(u(k)-k) - r_\ell k\right)^{1-\eta} \left(r_\ell k\right)^{\eta}. \tag{15}$$

The solution is such that k maximizes the total surplus, $(1-\theta)(u(k)-k)$, subject to $k \le v^{-1}(\tilde{m}+\chi\tilde{a})$. Since $u(k)-k$ increases in k until $k = q^*$, $k = \min\{v^{-1}(\tilde{m}+\chi\tilde{a}), q^*\}$. Observing that $v^{-1}(\tilde{m} + \chi\tilde{a}) \le q^*$ holds in equilibrium, the solution is given by

$$k = v^{-1}(\tilde{m} + \chi\tilde{a}), \tag{16}$$

$$r_\ell = \frac{\eta(1-\theta)(u(k)-k)}{k}. \tag{17}$$

3.4 Equilibrium

First start with the optimal behavior of a firm that finances through issuing corporate bonds. From (10), at a given price ψ, the firm chooses the amount of corporate bonds to issue, $A \ge 0$, that maximizes $(p_B - q_B) - (1-\psi)A$, which, using (12) and (13), reduces to $(1-\theta)(u(q_B) - q_B) - (1-\psi)A$, where $q_B = \min\{v^{-1}(\tilde{m} + \chi\tilde{a}), \psi A\}$ when believing that a consumer will carry $\tilde{m}$ amount of real balances and $\tilde{a}$ amount of corporate bonds to the DM. An equilibrium exists when $1 - \psi > 0$, or $\psi < 1$, that is, when borrowing through the corporate bond market is costly. Since the firm will not want to bring more capital to the DM than it needs to produce the amount of the DM goods that a consumer can afford, $v^{-1}(\tilde{m} + \chi\tilde{a})$, the maximization problem becomes

$$\max_{0 \le A \le v^{-1}(\tilde{m}+\chi\tilde{a})/\psi} \{(1-\theta)(u(\psi A) - \psi A) - (1-\psi)A\}. \tag{18}$$

The solution describes the optimal corporate bond issuance decision of the firm, or the supply of corporate bonds, and is given by

$$A = \min\{v^{-1}(\tilde{m} + \chi\tilde{a})/\psi, \bar{A}\} \tag{19}$$

where $\bar{A}$ solves

$$\frac{1}{\psi} - 1 = (1-\theta)(u'(\psi\bar{A}) - 1). \tag{20}$$

The amount of funds raised through issuing corporate bonds when $\bar{A} \leq v^{-1}(\tilde{m}+\chi\tilde{a})/\psi$, $\psi\bar{A}$, is

$$\psi\bar{A} = (u')^{-1}\left(\frac{1/\psi - 1}{1-\theta} + 1\right), \tag{21}$$

which is an increasing function of ψ, the price of the corporate bonds. The higher price makes financing through issuing corporate bonds less expensive and thus allows firms to raise more funds.

Now consider the optimal behavior of a consumer who chooses a portfolio of real balances and corporate bonds. From (2), the consumer chooses the amount of real balances, m, and the amount of corporate bonds, a, that maximize $-(1+\pi)m - \psi a + \beta V^C(m,a)$, which, using (4) and the linearity of W^C, becomes

$$\max_{m\geq 0, a\geq 0}\Big\{-(1+\pi)m - \psi a + \beta m + \beta a + \beta(1-\lambda)[u(q_L) - p_L] + \beta\lambda[u(q_B) - p_B]\Big\}. \tag{22}$$

Here I restrict attention to the case where the price of the corporate bonds, ψ, is not so high that firms will not be able to bring enough amount of intermediate goods to the DM to meet the consumers' demand.[12] In this case, $q_B = \psi\bar{A} < v^{-1}(m+\chi a)$, and $q_L = v^{-1}(m+\chi a)$ given (16). The consumer's maximization problem becomes

$$\max_{m\geq 0, a\geq 0}\Big\{-(1+\pi)m - \psi a + \beta m + \beta a + \beta(1-\lambda)\big[u(v^{-1}(m+\chi a)) - v(v^{-1}(m+\chi a))\big]\Big\}, \tag{23}$$

The optimal behavior of the consumer is given by

$$1+\pi = \beta\left\{1 + (1-\lambda)\left(\frac{u'(v^{-1}(m+\chi a))}{v'(v^{-1}(m+\chi a))} - 1\right)\right\}, \tag{24}$$

[12] This essentially means that i is assumed to be not too high (Assumption 1 given below). Online Appendix A.1 provides the characterization of the equilibrium outside this parameter space.

$$\psi = \beta \left\{ 1 + (1-\lambda)\chi \left(\frac{u'(v^{-1}(m+\chi a))}{v'(v^{-1}(m+\chi a))} - 1 \right) \right\}, \tag{25}$$

where the first is the consumer's money demand and the second is the consumer's bond demand. These expressions simplify to

$$i = (1-\lambda)L(m+\chi a), \tag{26}$$

$$\psi = \beta(1+\chi i). \tag{27}$$

where $i \equiv (1+\pi)/\beta - 1$ and $L(\cdot) \equiv u'(v^{-1}(\cdot))/v'(v^{-1}(\cdot)) - 1$ with $L'(\cdot) < 0$.

The following assumption ensures that the price of the corporate bonds is not too high so that financing through corporate bonds is expensive and that firms financing through corporate bonds are not able to satisfy the consumer's demand in the DM.

Assumption 1. $i < \bar{\imath} \equiv \dfrac{(1-\lambda)(1-\beta)\theta}{1-\theta+(1-\lambda)\beta\theta\chi}$.

Notice that this assumption implies that $i < (1-\beta)/(\beta\chi)$ so that $\psi < 1$ and thus also guarantees a well-defined bond supply function.

The equilibrium is defined as below.

Definition 1. *A steady state equilibrium of the economy corresponds to a constant sequence* $(q_L, q_B, m, a, A, \psi, k, r_\ell)$*, where* q_L *is the DM goods traded between a consumer and a firm that finances through borrowing from a bank,* q_B *is the DM goods traded between a consumer and a firm that finances through issuing corporate bonds,* m *is the consumer's real balance holdings,* a *is the consumer's corporate bond holdings,* A *is the supply of corporate bonds issued by firms,* ψ *is the price of corporate bonds,* k *is the size of a loan that a bank lends to a firm, and* r_ℓ *is the real lending rate of loans. Under Assumption 1,* (q_L, q_B) *satisfy*

$$q_L = v^{-1}\left(L^{-1}\left(\frac{i}{1-\lambda} \right) \right), \tag{28}$$

$$q_B = (u')^{-1}\left(\frac{1-\beta(1+\chi i)}{\beta(1+\chi i)(1-\theta)} + 1 \right), \tag{29}$$

(m, a, A, ψ) *satisfy*

$$\psi = \beta(1 + \chi i), \tag{30}$$

$$A = q_B/\psi, \tag{31}$$

$$a = \lambda A, \tag{32}$$

$$m = v(q_L) - \chi a, \tag{33}$$

and (k, r_ℓ) *satisfy*

$$k = q_L = v^{-1}(m + \chi a), \tag{34}$$

$$r_\ell = \frac{\eta(1-\theta)(u(k) - k)}{k}, \tag{35}$$

where

$$v(\cdot) = (1-\theta)u(\cdot) + \theta\,\cdot, \quad v'(\cdot) > 0, \tag{36}$$

$$L(\cdot) = u'(v^{-1}(\cdot))/v'(v^{-1}(\cdot)) - 1, \quad L'(\cdot) < 0. \tag{37}$$

3.5 Transmission Mechanism of Monetary Policy to Credit Costs

This section focuses on how monetary policy influences the cost of financing that in turn affects economic activity. First start with the price of the corporate bonds. From (30), $\partial\psi/\partial i > 0$. The nominal policy rate i affects the price of the corporate bonds through the cost of holding money (which equals i itself) and the liquidity premium of the corporate bonds (which equals $LP \equiv \chi i$ in (30)). As i increases, the rate of return on money decreases, and the real balances decrease. Due to less prevalent liquidity in the economy, the role of the corporate bonds as a medium of exchange increases, which in turn leads to an increase in the liquidity premium of the corporate bonds.

I define the excess bond premium following Gilchrist and Zakrajšek (2012), who compute the excess bond premium of a corporate bond as a difference between the yield of the corporate bond and the yield calculated using a price that equals the net present value of the cash flows, or the fundamental value, of the corporate bond.[13] For the one-period real corporate bond, the net present value of its cash flows is β, and the corresponding nominal yield is $i \equiv (1+\pi)/\beta - 1$, while the nominal yield of the corporate bond is $(1+\pi)/\psi - 1$. Hence, the excess bond premium (EBP) is given by

$$EBP = \left(\frac{1+\pi}{\psi} - 1\right) - i, \tag{38}$$

and

$$\frac{\partial EBP}{\partial i} = -\frac{\chi(1+i+i(1+\chi i))}{(1+\chi i)^2} < 0. \tag{39}$$

The negative impact of the nominal policy rate on the excess bond premium in this model comes through the effect of the nominal policy rate on the liquidity premium: the higher liquidity premium implies the smaller excess bond premium. I label this mechanism the liquidity premium channel of monetary policy transmission. Furthermore,

$$\frac{\partial \left|\dfrac{\partial EBP}{\partial i}\right|}{\partial \chi} = \frac{1+i(2-\chi)}{(1+\chi i)^3} > 0, \tag{40}$$

which means that the more liquid the corporate bond market, or the higher the degree of corporate bond liquidity, the stronger the liquidity premium channel.

Next consider how the nominal policy rate passes through to the real lending rate for loans. $\partial r_\ell/\partial k < 0$ from (35), $\partial k/\partial(m+\chi a) > 0$ from (34) and (36), and $\partial(m+\chi a)/\partial i < 0$ from (26) and (37). These together imply $\partial r_\ell/\partial i > 0$. From (16), with an increase in the nominal policy rate, the cost of holding money increases, agents carry less liquidity, and firms borrow less from a bank since agents can afford less. As a result, as can be seen from (17), the real loan rate increases because it depends positively on the marginal benefit of a loan, and the latter decreases in the loan size. The following proposition summarizes the discussion.

[13] Gilchrist and Zakrajšek (2012) define this difference as the credit spread, and define the excess bond premium as the credit spread after removing the component due to default risk. Since the corporate bonds in this model do not default, the credit spread equals the excess bond premium.

Proposition 1. *As the nominal policy rate increases, the liquidity premium of corporate bonds increases, the excess bond premium decreases, and the effect of the nominal policy on the excess bond premium becomes stronger as the corporate bond secondary market becomes more liquid. In addition, a higher nominal policy rate implies a higher price of corporate bonds and a higher real lending rate for loans:*

$$\frac{\partial LP}{\partial i} > 0, \quad \frac{\partial EBP}{\partial i} < 0, \quad \frac{\partial |\partial EBP/\partial i|}{\partial \chi} > 0, \quad \frac{\partial r_\ell}{\partial i} > 0. \tag{41}$$

3.6 Nominal Policy Rate

In the next section, I turn to the data and provide empirical evidence that supports the monetary policy transmission mechanism of the model summarized in Proposition 1. In the analysis of the model, as a nominal policy rate, I have used i, a nominal interest rate on a perfectly illiquid bond. However, in the empirical analysis, following the literature, I am going to use the Treasury rate as the nominal policy rate. The Treasuries are obviously considered highly liquid and thus their rate is a different object than i. In this subsection, before turning to the empirical analysis, I connect i and the Treasury rate, a nominal interest rate on a liquid government bond. To do so, assume that there are government bonds supplied at a fixed amount. Denote the nominal interest rate on the government bonds by i_g. Also, assume that those government bonds are partially liquid, and only a fraction $\chi_g \in (0, 1]$ can be used for liquidity purposes. In this case, in equilibrium, the nominal interest rate on the government bonds is given by

$$i_g = \frac{(1 - \chi_g)i}{1 + \chi_g i}, \quad \frac{\partial i_g}{\partial i} > 0. \tag{42}$$

That is, there is a one-to-one positive relationship between i and i_g. Hence, in the following empirical exercise, I adopt the Treasury rate as the policy rate.[14]

[14] Although theoretically it is possible to generate a negative relationship between i and i_g when one microfounds the asset secondary market in a rigorous way (see Geromichalos and Herrenbrueck (2017) for instance), Herrenbrueck (2019b) empirically shows that, except for Volcker's disinflation period in his first term (1981–1982), the estimated i and the nominal interest rate on the public debt are positively correlated. This gives me another justification for using the Treasury rate as the policy rate for the empirical analysis, given that the sample period of the dataset that I use starts from 1990.

4 Empirical Analysis

4.1 Structural Change in the Corporate Bond Market

4.1.1 Introduction of the TRACE and Its Impact on the Market Liquidity

Corporate bonds are traded between agents in the secondary market, which is a dealer-oriented over-the-counter (OTC) market. The trading environment of the U.S. corporate bond secondary market used to be highly opaque for decades. Transaction-related information, such as prices and volumes at which corporate bonds were traded, was available only to the parties involved in the transactions. This caused an asymmetric information problem between dealers and traders, and dealers extracted rents from less-informed customers. These rent-seeking behaviors of dealers incurred traders a huge amount of trading costs and made the market illiquid.[15]

However, the scene changed dramatically when the Transaction Reporting and Compliance Engine (TRACE) was introduced to the U.S. corporate bond market, and many of the issues that were hindering the market from being liquid were resolved. With the approval of the Securities and Exchange Commission (SEC), beginning on July 1, 2002, the National Association of Security Dealers (NASD) (which is currently the Financial Industry Regulatory Authority (FINRA)) started to require dealers to report transaction-related information on all over-the-counter trades for publicly issued corporate bonds, such as the identification of traded bonds, the date and the time of execution, trade size, trade price, yields, and whether the dealers bought or sold in the transaction. The TRACE is the platform that the NASD developed to facilitate this mandatory reporting.

The amount of the information made public and the timeliness of reporting under the new system were phased in over time from July 1, 2002 to January 9, 2006 based on the size and the credit rating of the bonds. On July 1, 2002, trades in investment-grade corporate bonds with an issuance size of $1 billion or greater, as well as 50 representative non-investment-grade bonds, began to be disseminated to the public. During 2003, trades in 120 selected BBB-rated bonds (on April 14, 2003) and higher-rated bonds (on March 3,

[15] Biais and Green (2019) provide detailed discussion on how the opaque transaction environment deteriorated the corporate bond secondary market in terms of trading costs and the market liquidity.

2003) with initial issue sizes over \$100 million began to be disseminated to the public. On February 7, 2005, data began to be disseminated for all but newly issued or lightly traded bonds. By January 9, 2006, trades in all publicly issued bonds were disseminated to the public. In addition, the timeliness with which dealers were required to report trades was tightened in stages. Upon the introduction of TRACE, dealers had 75 minutes to report trades. This was reduced on October 1, 2003, to a reporting time of 45 minutes, and on October 1, 2004, to 30 minutes. Since July 1, 2005, dealers have been required to report trades within 15 minutes. Since January 9, 2006, reports have had to be made immediately.[16]

Empirical evidence shows that the post-trade transparency due to the introduction of the TRACE reduced dealers' information advantage relative to traders, led to a significant drop in trading costs, and substantially improved the market liquidity. For example, three papers, Bessembinder, Maxwell, and Venkataraman (2006), Edwards, Harris, and Piwowar (2007), and Goldstein, Hotchkiss, and Sirri (2007) examine how the market liquidity, measured in bid-ask spreads, changed around the period when the TRACE was implemented, and find that the secondary market liquidity increased by 50–84% with the mandatory transaction reporting system. The empirical literature documents this substantial improvement in the market liquidity with the introduction of the TRACE as a structural change in the U.S. corporate bond market.

4.1.2 Hypotheses

The increased liquidity of the corporate bond secondary market with the introduction of the TRACE can be interpreted as an increase in χ in the model, the fraction of corporate bond holdings that can be used towards trades for liquidity purposes, which essentially is capturing the degree of the secondary market liquidity. This in turn implies that, as Proposition 1 states, the liquidity premium channel of monetary policy transmission must be stronger in the period after the TRACE was implemented.

My model was focusing mainly on how monetary policy affects the corporate bond premium through the liquidity premium of the corporate bonds, and, through this channel,

[16] For more details on the history of the implementation of the TRACE, see Bessembinder and Maxwell (2008) and Asquith, Covert, and Pathak (2013).

a higher nominal policy rate decreases the corporate bond premium, as in Proposition 1. However, there is other channel as well through which monetary policy can influence the corporate bond premium. According to the literature on the credit channel of monetary policy transmission, when financial market imperfections are present, a higher nominal policy rate increases the corporate bond premium by tightening credit constraints and subsequently affecting firms' ability to borrow.[17] This means that the end effect of monetary policy on the corporate bond premium depends on the relative strength of the (negative) liquidity premium channel and the (positive) credit channel.

Gertler and Karadi (2015) find that an increase in the nominal policy rate increases the corporate bond premium using the data with the sample period 1979–2012. This suggests that, during that overall period, the credit channel is stronger than the liquidity premium channel. Noting that the liquidity premium channel must be stronger during the post-TRACE period, I make the following hypotheses. When the effect of an increase in the nominal policy rate is positive in the overall period, the magnitude of the effect should be larger during the pre-TRACE period when the negative liquidity premium channel barely exists. On the other hand, the magnitude of the effect should be smaller during the post-TRACE period when the negative liquidity premium channel is active. Or, the effect could potentially be overturned and become negative if the liquidity premium channel is strong enough.

In the empirical analysis in the following sections, I test the hypotheses and show that this is the case. In Section 4.2, I compare the effect of monetary policy on the corporate bond premium across the two periods before and after the introduction of the TRACE. In doing so, the liquidity premium channel is identified by the difference in the effects across two periods. In Section 4.3, I measure the liquidity premium channel using more direct liquidity measures, such as bid-ask spreads and trading volume. In Section 4.4, I examine how bank loan rates respond to monetary policy changes. These altogether provide empirical support to Proposition 1.

[17] See for instance Bernanke and Gertler (1989), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999).

4.2 Corporate Bond Premium and Monetary Policy Shocks

4.2.1 Empirical Framework

For the corporate bond premium, I use the excess bond premium measured by Gilchrist and Zakrajšek (2012), which is an extracted component of credit spreads that is not directly attributable to the expected default risk. I estimate the dynamic response of the excess bond premium to a monetary policy shock. I use the structural vector autoregression with external instruments (SVAR-IV) that was introduced by Stock (2008) and Mertens and Ravn (2013), and apply it to monetary policy, following Gertler and Karadi (2015). The SVAR-IV includes four variables: the 1-year Treasury constant maturity rate (as the policy rate), industrial production (100 times log of it), the consumer price index (100 times log of it), and the excess bond premium. To ensure the results are not driven by other macro factors and to limit any potential reverse causality issues, as exogenous variations in the policy rates, I use three-month-ahead financial market surprises from Federal Funds futures in a 30-minute window around the Federal Open Market Committee policy announcements, constructed by Gertler and Karadi (2015). In addition, I use the local projection instrumental variable (LP-IV) approach, following Jordà (2005), Jordà, Schularick, and Taylor (2020). The baseline specification for horizon h is $y_{t+h} - y_{t-1} = \alpha^h + \beta^h r_t + u_{t+h}$, where y are the main variables, r is the policy rate that is instrumented, and β^h refers to the impulse response at horizon h. The same four variables and instruments are used for estimation.

The sample period spans 1990:2–2016:12 with monthly frequency. For both SVAR-IV and LP-IV specifications, 12-month lags of the four main variables and 4-month lags of the instrument are used as control variables, following Gertler and Karadi (2015). I do the unit effect normalization following Stock and Watson (2018) for direct estimation of the dynamic causal effect in the native units relevant to policy analysis. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap for SVAR-IV following Stock and Watson (2018), and using the Newey-West heteroskedastic and autocorrelation consistent standard errors for LP-IV. For each point estimate along the horizons, the 95% confidence interval is given.

To examine potentially different effects of monetary policy shocks on the excess bond

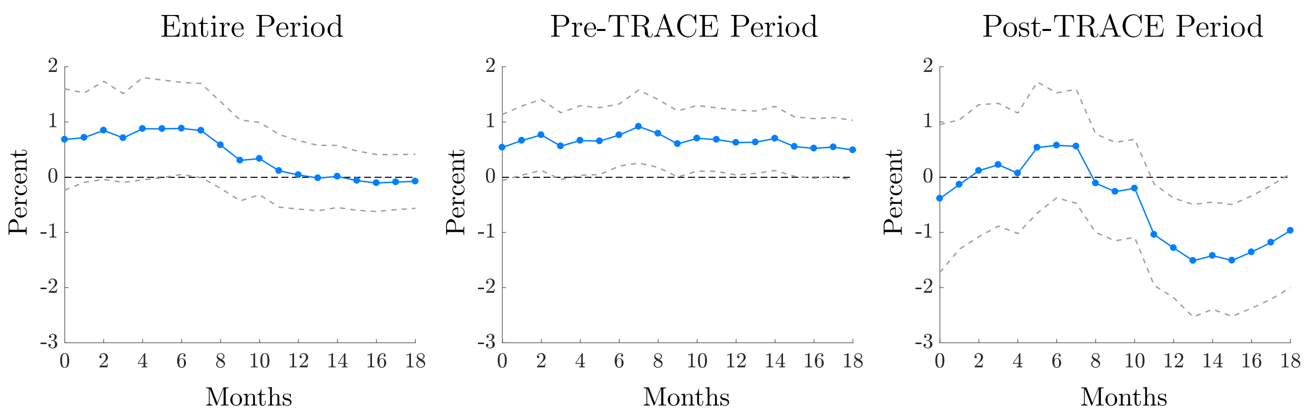

Figure 2. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using SVAR-IV with unit effect normalization. Sample period: 1990:2–2016:12; pre-TRACE period: 1990:2–2003:2; post-TRACE period: 2003:3–2016:12. Dashed lines are the 95% confidence interval.

premium before and after the introduction of the TRACE, I divide the sample period into two: 1990:2–2003:2 for the pre-TRACE period and 2003:3–2016:12 for the post-TRACE period. Considering the fact that required reporting of corporate bond transactions to the public was phased in over the period 2002:7–2006:1, I choose the midpoint 2003:3 as a benchmark when the mandatory reporting was imposed on a significant portion of corporate bonds. I check that the results are robust to alternative breakpoints.

4.2.2 Results

The response of the excess bond premium to a one-percent increase in the nominal policy rate estimated using SVAR-IV is given in Figure 2, and the response estimated using LP-IV is given in Figure 3. In both Figures 2 and 3, the left panel is for the entire period, the middle panel is for the pre-TRACE period, and the right panel is for the post-TRACE period. To ensure that the instrument is valid, I check the heteroscedasticity-robust F-statistic from the first-stage regression, and all are safely above the threshold suggested by Stock, Wright, and Yogo (2002) to rule out a reasonable likelihood of a weak instruments problem.

Monetary policy shock considered is a one-percent increase in the 1-year Treasury constant maturity rate, which I consider as the policy rate. When estimated using the entire sample, consistent with the results of Gertler and Karadi (2015), the excess bond premium increases following a one-percent increase in the nominal policy rate. However, the response

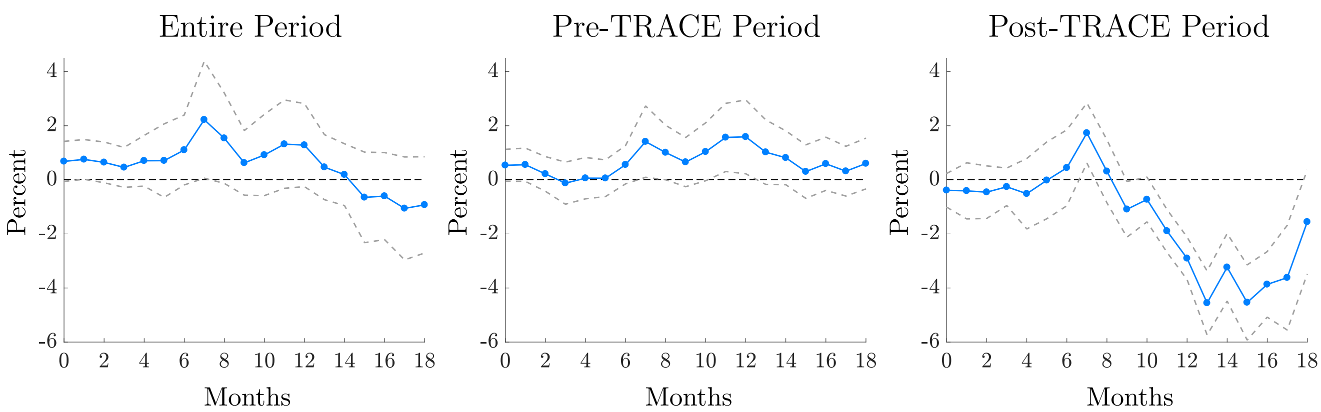

Figure 3. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using LP-IV with unit effect normalization. Sample period: 1990:2–2016:12; pre-TRACE period: 1990:2–2003:2; post-TRACE period: 2003:3–2016:12. Dashed lines are the 95% confidence interval.

of the excess bond premium is different when we look at the two different periods: the pre- and the post-TRACE periods. For the pre-TRACE period, the positive response of the excess bond premium to a one-percent increase in the nominal policy rate appears more persistent and significant. On the other hand, for the post-TRACE period, the response of the excess bond premium is not just less strong but it becomes negative. These results are consistent with the hypotheses. The whole period covers both the pre-TRACE period where the negative liquidity premium channel is less effective and the post-TRACE period where the negative liquidity premium channel is more effective. It turns out that during the post-TRACE period the negative liquidity premium channel is strong enough to dominate the positive credit channel.

4.2.3 Sensitivity Analysis

This section checks the robustness of the decline in the excess bond premium following an increase in the nominal policy rate during the post-TRACE period.

Factor-augmented LP-IV. As Stock and Watson (2018) point out, if there are more than four shocks that affect the four variables, or if some elements of the four variables are measured with error (such as industrial production, the consumer price index, or the inflation rate), including additional variables that are correlated with the shocks could increase the precision of the estimation. As suggested by Stock and Watson (2018), I add lags of principal components, or factors, computed from the FRED-MD database by McCracken and Ng (2016) to the LP-IV setting. The response of the excess bond premium to a one-percent increase in the nominal policy rate estimated using factor-augmented LP-IV is given in Figure B1. The additional controls yield results that are consistent with (and stronger than) the results estimated using LP-IV.

Test for a structural break. To test a structural break induced by the introduction of the TRACE, I interact all the regressors in LP-IV and factor-augmented LP-IV with the post-TRACE year dummy. Figure B2 shows the base and the post-TRACE responses of the excess bond premium to a one-percent increase in the nominal policy rate estimated using LP-IV, and Figure B3 estimates the responses using factor-augmented LP-IV. As can be seen, an increase in the nominal policy rate has a negative impact for the post-TRACE period. Although the negative impact is not significant in the early horizons, the null hypothesis of no structural break is rejected for all horizons with p-value 0 for both LP-IV and factor-augmented LP-IV.

Zero lower bound. The sample period, especially the post-TRACE period, includes the Great Recession, and, during that period, the short-term interest rate reached the zero lower bound. However, Swanson and Williams (2014) argue that the zero lower bound was not a constraint on the Federal Reserve's ability to manipulate the 2-year rate, which might have been probably less true for the 1-year rate. To address the concern about the zero lower bound, I show the results are robust to using the 2-year Treasury constant maturity rate, instead of the 1-year rate, although, as Gertler and Karadi (2015) point out, the 2-year rate is less relevant with the instrument in the first-stage regression compared to the 1-year rate and thus suffers the weak instruments problem. Figure B4, B5 and B6 show the response of the excess bond premium to a one-percent increase in the nominal policy rate for the entire period, the pre-TRACE period, and the post-TRACE period, respectively using LP-IV, factor-augmented LP-IV, and SVAR-IV, using the 2-year rate. All the results are consistent with those using the 1-year rate.

Estimates during the shorter period around the introduction of the TRACE. Another concern over the fact that the sample period, especially the post-TRACE period, includes the Great Recession is that it was a very different time in terms of monetary policy, for example, in that the central bank used unconventional credit market interventions such as a series of quantitative easing to affect market interest rates. This therefore implies that the pre- and the post-TRACE periods are different not just because of the introduction of the TRACE but because of all that was happening during and after the crisis. To address this concern and to make the pre- and the post-TRACE periods as similar as possible except for the existence of the TRACE, I narrow the sample period to a shorter window around the introduction of the TRACE to exclude the 2008:7–2009:6 crisis period. I consider 1997:11–2003:2 as the pre-TRACE period and 2003:3–2008:6 as the post-TRACE period. Due to the singularity problem with the long lag length, I decrease the lag length of the four main variables to 4 months and that of the instrument to 2 months. Figure B7 shows the response of the excess bond premium to a one-percent increase in the nominal policy rate for the entire period, the pre-TRACE period, and the post-TRACE period using LP-IV during the shorter sample period. Although the small sample size generates large standard errors and using the short lag length is subject to a weak instruments problem, the results, especially the one for the post-TRACE period, suggest the decline in the excess bond premium following a one-percent increase in the nominal policy rate when the negative liquidity premium channel is active and strong. Figure B8 and B9 perform the same exercise using SVAR-IV. Even with the shorter sampler period that does not include the recent crisis, the responses of the excess bond premium to a one-percent increase in the nominal policy rate during the pre- and the post-TRACE periods are extremely contrasting and significant, with the former during the pre-TRACE period being the exact same as in Gertler and Karadi (2015) and the latter during the post-TRACE period being a total opposite.

Different lag lengths. I check the robustness of the results with different lag lengths. When the lag length of the main variables is shorter than 9 months, the first-stage regression suffers a weak instruments problem with both the F-statistic the robust F-statistic being less than the threshold suggested by Stock, Wright, and Yogo (2002). For a lag length longer than or equal to 9 months (I checked up to 24 months), the results remain consistent.

Alternative breakpoints. The obvious alternative breakpoint is 2002:7 when the mandatory reporting was first executed. All the results discussed remain the same. Using other breakpoints such as 2003:4 (when the mandatory reporting was applied to additional 120 selected BBB-rated bonds), 2005:2 (when the mandatory reporting was applied to all but newly issued or lightly traded bonds) or 2006:1 (when transaction information for all publicly issued bonds started to be made public) also does not change the results at all.

4.3 Liquidity Premium and Monetary Policy Shocks

In the previous section, the liquidity premium channel of monetary policy transmission is identified indirectly by the difference of the effects of monetary policy on the corporate bond premium across the pre- and the post-TRACE periods. In this section, I measure the liquidity premium channel using direct liquidity measures such as bid-ask spreads and trading volume.

4.3.1 Empirical Framework

I add a liquidity measure of corporate bonds to the SVAR-IV and the LP-IV setups described in the previous section. The two most common liquidity measures are bid-ask spreads and trading volume. The measures are based on corporate bond transaction data from the TRACE database. I follow Adrian, Fleming, Shachar, and Vogt (2017) in calculating the measures. The bid-ask spreads compute average daily bid-ask spreads by month across bonds. First, spreads are calculated daily for each bond as the difference between the average (volume-weighted) dealer-to-client buy price (the price at which dealers are willing to buy, or bid) and the average (volume-weighted) dealer-to-client sell price (the price at which dealers are willing to sell, or ask). Then, the spreads are averaged across bonds using equal weighting and across days for each month. The trading volume computes the average daily trading volume by month across bonds. Both liquidity measures enter the specification as 100 times log of them. Because to compute the liquidity measures I use the TRACE database that exists only after the TRACE was introduced, naturally this section focuses solely on the post-TRACE period.

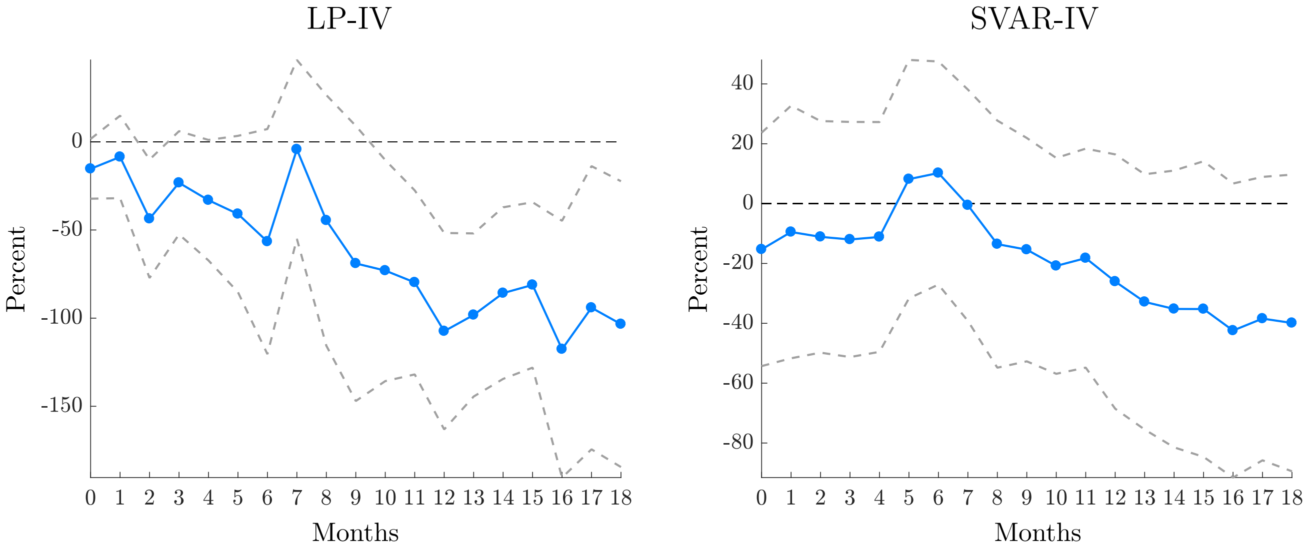

Figure 4. Response of the bid-ask spreads of corporate bonds to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using LP-IV and SVAR-IV with unit effect normalization. Sample period: 2003:3–2016:12. Dashed lines are the 95% confidence interval.

4.3.2 Results

The more liquid corporate bonds, the narrower the bid-ask spreads, and the larger the trading volume. In other words, liquidity and the bid-ask spreads are negatively correlated, while liquidity and the trading volume are positively correlated. For all results, I check the heteroscedasticity-robust F-statistic from the first-stage regression to ensure that the results are not subject to a weak instruments problem, and all are safely above the threshold suggested by Stock, Wright, and Yogo (2002). The monetary policy shock considered is a one-percent increase in the 1-year Treasury constant maturity rate. Figure 4 estimates the response of the bid-ask spreads to a one-percent increase in the nominal policy rate using SVAR-IV and LP-IV. In both panels, the bid-ask spreads decrease following a one-percent increase in the nominal policy rate. Figure 5 estimates the response of the trading volume to a one-percent increase in the nominal policy rate using SVAR-IV and LP-IV. In both panels, the trading volume increases following a one-percent increase in the nominal policy rate. For both the bid-ask spreads and the trading volume, the responses are not significant for SVAR-IV, but the responses are highly significant for LP-IV. The results support the negative liquidity premium channel of monetary policy transmission and are consistent with

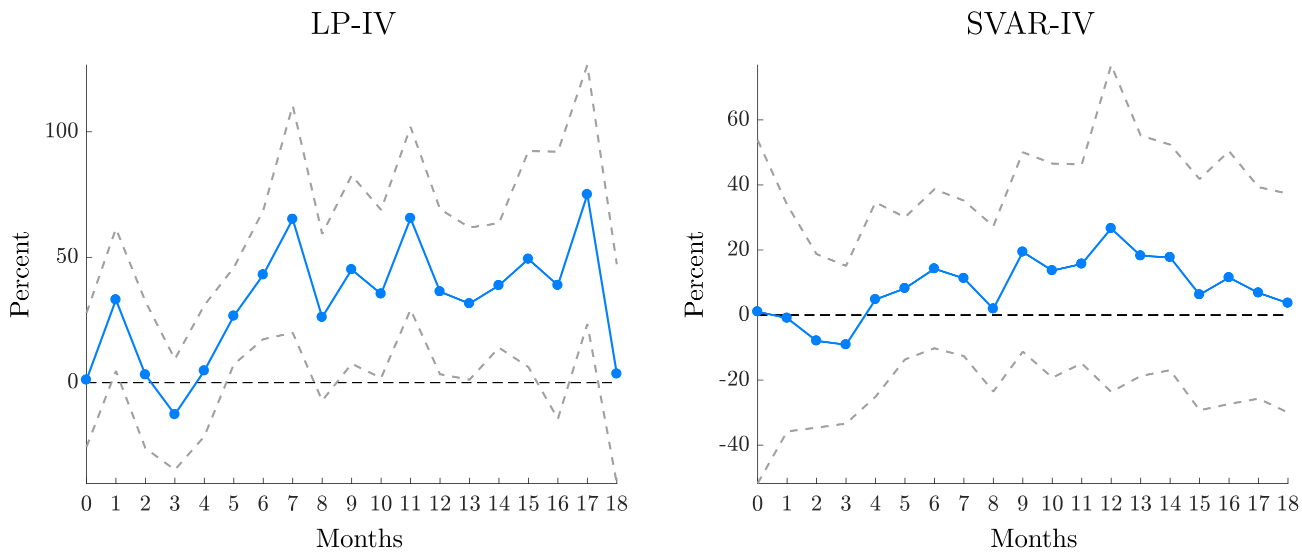

Figure 5. Response of the trading volume of corporate bonds to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using LP-IV and SVAR-IV with unit effect normalization. Sample period: 2003:3–2016:12. Dashed lines are the 95% confidence interval.

the theory that suggests that a one-percent increase in the nominal policy rate increases the liquidity premium of corporate bonds.

4.3.3 Sensitivity Analysis

This section checks the robustness of the positive response of the liquidity premium to a one-percent increase in the nominal policy rate, following the checklists from Section 4.2.3. I augment the LP-IV setting with the macroeconomic factors from the FRED-MD database by McCracken and Ng (2016). The responses of the liquidity measures to a one-percent increase in the nominal policy rate estimated by factor-augmented LP-IV are given in Figure B10. While the response of the trading volume is less clear, the response of the bid-ask spreads is consistent with (and stronger than) the results estimated using LP-IV. To address the concern over the 1-year rate hitting the zero lower bound during the Great Recession, I estimate the response of both the liquidity measures to a one-percent increase in the nominal policy rate using LP-IV and SVAR-IV with the 2-year Treasury constant maturity rate instead of the 1-year rate. Figure B11 and B12 show the response of the bid-ask spreads and the trading volume, respectively. Although, as Gertler and Karadi (2015) point out, the 2-year rate is less relevant with the instrument in the first-stage regression compared to the 1-year rate and thus suffers the weak instruments problem, all the results are consistent with those using the 1-year rates. The results also remain the same when using different lag lengths for the lag length that does not suffer a weak instruments problem (longer than or equal to 10 months for the bid-ask spreads and 7 months for the trading volume). Using alternative breakpoints does not change the results either.

4.4 Bank Loan Rates and Monetary Policy Shocks

This section provides the empirical evidence that an increase in the nominal policy rate raises real bank loan rates, as opposed to the case of corporate bonds.

4.4.1 Empirical Framework

I add the business loan rate to the SVAR-IV and the LP-IV setups described in Section 4.2. In particular, the real rate is of my interest and I calculate it as the nominal loan rate minus the expected inflation rate. The nominal loan rate is the bank business prime loan rate, and the expected inflation rate is the 5-year forward inflation expectation rate from the Federal Reserve Economic Data (FRED) from the Federal Reserve Bank of St. Louis. The expected inflation rate series exists from 2003, so the sample period considered in this section is the post-TRACE period.

4.4.2 Results

The heteroscedasticity-robust F-statistics from the first-stage regressions ensure that the results are not subject to a weak instrument problem, and all are safely above the threshold suggested by Stock, Wright, and Yogo (2002). The monetary policy shock considered is a one-percent increase in the 1-year Treasury constant maturity rate. Figure 6 estimates the response of the real loan rate to a one-percent increase in the nominal policy rate using SVAR-IV and LP-IV. In both panels, following a one-percent increase in the nominal policy rate, the real bank loan rate increases, and the estimates are significant.

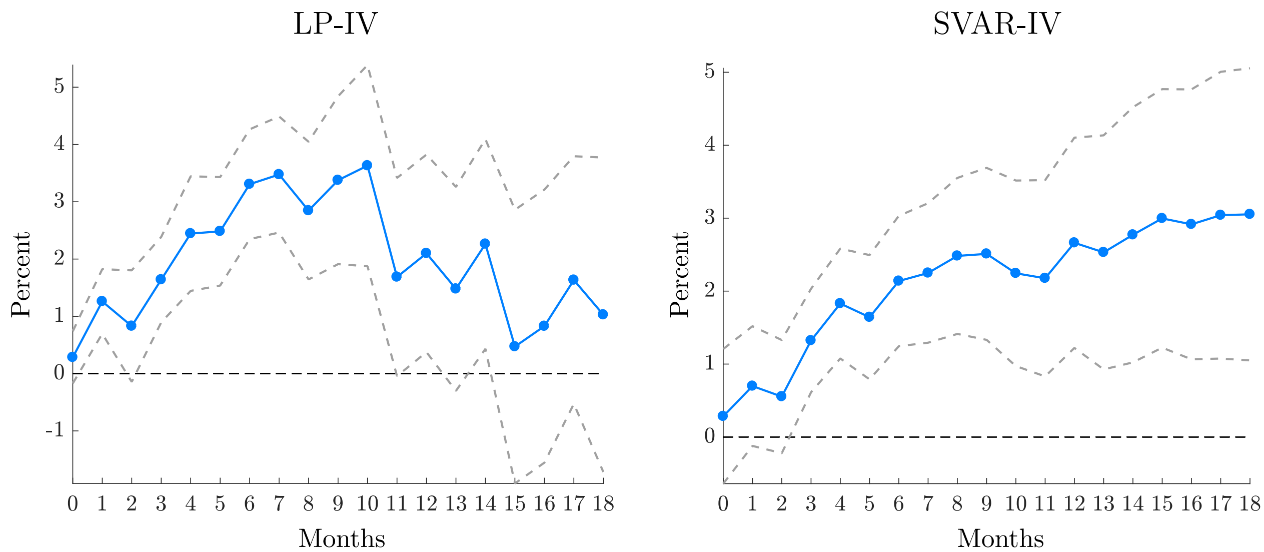

Figure 6. Response of the real loan rate to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using LP-IV and SVAR-IV with unit effect normalization. Sample period: 2003:3–2016:12. Dashed lines are the 95% confidence interval.

4.4.3 Sensitivity Analysis

This section checks the robustness of the positive response of the real bank loan rate to a one-percent increase in the nominal policy rate, following the checklists from Section 4.2.3. I augment the LP-IV setting with the macroeconomic factors from the FRED-MD database by McCracken and Ng (2016). The response of the real bank loan rate to a one-percent increase in the nominal policy rate estimated by factor-augmented LP-IV is given in Figure B13. The results are consistent with those using LP-IV. To address the concern over the 1-year rate hitting the zero lower bound during the Great Recession, I estimate the response of the real bank loan rate to a one-percent increase in the nominal policy rate using LP-IV and SVAR-IV with the 2-year Treasury constant maturity rate instead of the 1-year rate. Although, as Gertler and Karadi (2015) point out, the 2-year rate is less relevant with the instrument in the first-stage regression compared to the 1-year rate and thus suffers the weak instruments problem, the results are in Figure B14 and all are consistent with those using the 1-year rates. The results also remain the same when using different lag lengths for the lag length that does not suffer a weak instruments problem (longer than or equal to 6 months). Using alternative breakpoints does not change the results either.

5 Compositional Effect of Monetary Policy on Credit

In this section, I examine how monetary policy changes induce a shift in the composition of credit between corporate bonds and loans at the firm level. While previously the measure $\lambda \in (0,1)$ of firms were assumed to finance solely through issuing corporate bonds, now those firms that have access to the corporate bond market can also try to obtain a loan from a bank. In addition, a firm meets, or can find, a bank that is willing to give a loan with probability $\alpha \in (0,1)$, as in Rocheteau, Wright, and Zhang (2018). α can be thought of as a loan application acceptance rate. This means that, among the measure λ of the firms that have access to the corporate bond market, $\alpha\lambda$ will be able to finance through both issuing corporate bonds and obtaining a bank loan. In such case, I assume firms will first decide how many corporate bonds to issue and then go to the OTC market for bank loans.[18] The other $(1-\alpha)\lambda$ will not be able to find a bank that is willing to give a loan and thus will have to finance investment only through issuing corporate bonds. $(1-\alpha)(1-\lambda)$ among the measure $1-\lambda$ of the firms that do not have access to the corporate bond market will not be able to borrow from a bank and thus cannot produce any in the first subperiod. To simplify the presentation, I normalize the measure of consumers to $\alpha + (1-\alpha)\lambda$ so that all the consumers match with a firm in bilateral meetings in the DM.

5.1 Value Functions

The value functions of suppliers remain the same as before. A bank in the second subperiod randomly matches with a firm, and there are two types of firms: one that has access to the corporate bond market and the other that does not. Denote the terms of a loan contract between a bank and a firm that cannot issue corporate bonds by (k^L, r_ℓ^L) and the terms of a loan contract between a bank and a firm that can issue corporate bonds by (k^B, r_ℓ^B). The value function of a bank that is willing to give a loan to a firm that cannot issue corporate

[18] The timing of events is important in getting the desired result that firms use both ways of financing when they have access to both the corporate bond and the bank loan markets. If it is assumed that firms first go to the OTC market for bank loans and then turn to the corporate bond market, then they will not issue any corporate bonds. See Online Appendix A.2 for details.

bonds is

$$W^B(w) = \max_c c + \beta W^B((1 + r_\ell^L)k^L) \quad \text{s.t.} \quad c + k^L = w, \tag{43}$$

and the value function of a bank that is willing to give a loan to a firm that can issue corporate bonds is

$$W^B(w) = \max_c c + \beta W^B((1 + r_\ell^B)k^B) \quad \text{s.t.} \quad c + k^B = w. \tag{44}$$

The value function of a firm that does not have access to the corporate bond market and thus has to borrow from a bank to finance investment remains the same as before, as in (7) and (8), but now the terms of a loan contract are denoted by (k^L, r_ℓ^L). The value function of a firm that has access to the corporate bond but could not borrow from a bank is the same as that of a firm that finances investment solely by issuing corporate bonds, as in (9) and (10).

Consider a firm that has access to the corporate bond market and also finds a bank that is willing to give a loan. The terms of a loan contract are denoted by (k^B, r_ℓ^B). The value function in the first subperiod of the firm that issued $\hat{A}$ amount of corporate bonds at price ψ and that obtained k^B amount of a loan from a bank at a real lending rate r_ℓ^B in the previous second subperiod is

$$V^F(\psi\hat{A} + k^B, \hat{A} + (1 + r_\ell^B)k^B) = W^F(\psi\hat{A} + k^B - q, p, \hat{A} + (1 + r_\ell^B)k^B), \tag{45}$$

where (p, q) are the terms of trade in the following DM. The value function of a firm in the second subperiod after trading in the DM is

$$\begin{gathered} W^F(\psi\hat{A} + k^B - q, p, \hat{A} + (1 + r_\ell^B)k^B) = \max_c c \\ \text{s.t.} \quad c = \psi\hat{A} + k^B - q + p - \hat{A} - (1 + r_\ell^B)k^B, \end{gathered} \tag{46}$$

which simply reduces to $W^F(\psi\hat{A}+k^B-q, p, \hat{A}+(1+r_\ell^B)k^B) = \psi\hat{A}+k^B-q+p-\hat{A}-(1+r_\ell^B)k^B$. Using the linearity of W^F, a newborn firm in the second subperiod with a loan contract

(k^B, r_ℓ^B) decides the amount of corporate bonds to issue by solving

$$\max_{\hat{A}\geq 0} \beta V^F(\psi \hat{A} + k^B, \hat{A} + (1 + r_\ell^B)k^B) = \max_{\hat{A}\geq 0} \beta\{(p - q) - (1 - \psi)\hat{A} - r_\ell^B k^B\}. \tag{47}$$

A consumer in the DM matches with a firm that does not have access to the corporate bond market but was able to borrow from a bank with probability $\alpha(1-\lambda)/(\alpha + (1-\alpha)\lambda)$, a firm that has access to the corporate bond market and also was able to borrow from a bank with probability $\alpha\lambda/(\alpha + (1-\alpha)\lambda)$, and a firm that has access to the corporate bond market but was not able to borrow from a bank with probability $(1-\alpha)\lambda/(\alpha + (1-\alpha)\lambda)$. The value function of a consumer who brings $\hat{m}$ amount of real balances and $\hat{a}$ amount of corporate bonds to the DM is

$$\begin{aligned} V^C(\hat{m}, \hat{a}) = {} & \frac{\alpha(1-\lambda)}{\alpha + (1-\alpha)\lambda}\left[u(q_L) - p_L\right] + \frac{\alpha\lambda}{\alpha + (1-\alpha)\lambda}\left[u(q) - p\right] + \frac{(1-\alpha)\lambda}{\alpha + (1-\alpha)\lambda}\left[u(q_B) - p_B\right] \\ & + W^C(\hat{m} + \hat{a}). \end{aligned} \tag{48}$$

5.2 Loan Contract

Now there are two types of meetings in the OTC market for loans in the second subperiod: one between a bank and a firm that does not have access to the corporate bond market, and the other between a bank and a firm that has access to the corporate bond market and thus has issued corporate bonds before entering the OTC market for loans. The bargaining problem in the former meeting is the same as in the previous environment, and the solution is given by (16) and (17).

In the latter meeting, a bank and a firm bargain over the terms of a loan contract, (k^B, r_ℓ^B). Consider a meeting between a bank and a firm that has already raised ψA amount of funds by issuing A amount of corporate bonds at price ψ. I restrict attention as in Section 3.4 under Assumption 1 to the case where the price of the corporate bonds is not too high so that financing through corporate bonds is expensive and that firms financing through corporate bonds are not able to satisfy the consumer's demand in the DM. The firm's continuation value with a loan contract (k^B, r_ℓ^B) is $\beta V^F(\psi A + k^B, A + (1 + r_\ell^B)k^B)$, and the firm's continuation value without a loan contract is $\beta V^F(\psi A, A)$. Thus, the firm's surplus is $\beta[V^F(\psi A+k^B, A+(1+r_\ell^B)k^B)-V^F(\psi A, A)]$. Given that firms will not raise funds more than what they need to satisfy the consumer's demand, using (12), (13) and (45), this reduces to $[(1-\theta)(u(\psi A+k^B)-(\psi A+k^B))-(1-\psi)A-r_\ell^B k^B]-[(1-\theta)(u(\psi A)-\psi A)-(1-\psi)A]$ subject to $k^B \leq v^{-1}(\tilde{m}+\chi\tilde{a})-\psi A$, when the firm and the bank believe that a consumer will carry $\tilde{m}$ amount of real balances and $\tilde{a}$ amount of corporate bonds to the DM. The bank's surplus is $\beta r_\ell k$ as before. The terms of a loan contract specify (k^B, r_ℓ^B) that solves

$$\max_{k^B \leq v^{-1}(\tilde{m}+\chi\tilde{a})-\psi A, r_\ell} \left[r_\ell k\right]^\eta \times \tag{49}$$
$$\left[\left((1-\theta)(u(\psi A+k^B)-(\psi A+k^B))-(1-\psi)A-r_\ell^B k^B\right)-\left((1-\theta)(u(\psi A)-\psi A)-(1-\psi)A\right)\right]^{1-\eta}.$$

The solution is such that k maximizes the total surplus, $(1-\theta)[u(\psi A+k^B)-u(\psi A)-k^B]$, subject to $k^B \leq v^{-1}(\tilde{m}+\chi\tilde{a})-\psi A$. The solution is given by

$$k^B = v^{-1}(\tilde{m}+\chi\tilde{a})-\psi A, \tag{50}$$
$$r_\ell^B = \eta(1-\theta)\left[\frac{u(\psi A+k^B)-u(\psi A)}{k^B}-1\right]. \tag{51}$$

5.3 Bond Supply

From (12), (13), (47), (50) and (51), at a given price ψ, the firm chooses the amount of corporate bonds to issue, $A \geq 0$, to maximize

$$\max_A (1-\theta)[u(v^{-1}(m+\chi a))-v^{-1}(m+\chi a)]-(1-\psi)A-r_\ell^B k^B, \tag{52}$$

which is equivalent to maximizing

$$\max_A \eta(1-\theta)[u(\psi A)-\psi A]-(1-\psi)A. \tag{53}$$

The solution describes the optimal corporate bond issuance decision of the firm, or the supply of corporate bonds, which is given by

$$\frac{1}{\psi}-1 = \eta(1-\theta)(u'(\psi\bar{A})-1), \tag{54}$$

and the amount of funds that firms will raise by issuing corporate bonds, ψA, is

$$\psi A = (u')^{-1}\left(\frac{1/\psi - 1}{\eta(1-\theta)} + 1\right). \tag{55}$$

5.4 Composition of Credit

Now I examine the optimal composition of credit between corporate bonds and bank loans at the firm level. The result in (55) shows that a firm wants to issue some amount of corporate bonds before entering the OTC market for bank loans. The intuition is as follows. From (51), r_ℓ^B is an increasing function of ψA. This is because firms with large corporate bond issuance rely less on bank loans (as can be seen from (50) that k^B is decreasing in ψA) and can negotiate for a lower real loan rate (as can be seen from (51) that r_ℓ^B is decreasing in k^B). The benefit of issuing corporate bonds in negotiating for a bank loan is the first term in (53), $\eta(1-\theta)[u(\psi A) - \psi A]$, which comes from $-r_\ell^B k^B$ in (52). The cost side of issuing corporate bonds is the second term in (53), $-(1-\psi)A$, the liabilities that the firm needs to pay to the consumers who are holding the corporate bonds. The concave benefit function and the linear cost function together determine the optimal composition of credit as in (50) and (55).

Monetary policy changes affect this composition of credit between corporate bonds and bank loans. A higher nominal policy rate, i, decreases the total size of credit as the consumer's demand declines due to the higher cost of holding liquidity, as can be seen from (50) that $\psi A + k^B$ equals $v^{-1}(m + \chi a)$ which in turn is a decreasing function of i from (26). On the other hand, at the same time, as is explained in Section 3.5 and Proposition 1 says, a higher nominal policy rate makes issuing corporate bonds less expensive, allowing firms to issue more corporate bonds for the strategic purpose of lowering their financing costs, as can be seen from (55) that the left-hand side, ψA, is an increasing function of ψ which in turn is an increasing function of i. As a result, with a higher nominal policy rate, firms borrow less from banks. Therefore, as the nominal policy rate increases, the portion of corporate bonds among the total credit becomes larger, and that of bank loans becomes smaller. The following proposition summarizes the discussion.

Proposition 2. *As the nominal policy rate increases, the size of total credit decreases. Among the total credit that becomes smaller, firms increase the portion of credit from issuing corporate bonds and decrease that from bank loans:*

$$\frac{\partial(\psi A + k^B)}{\partial i} < 0, \quad \frac{\partial \psi A}{\partial i} > 0, \quad \frac{\partial k^B}{\partial i} < 0, \quad \frac{\partial\left(\dfrac{\psi A}{\psi A + k^B}\right)}{\partial i} > 0, \quad \frac{\partial\left(\dfrac{k^B}{\psi A + k^B}\right)}{\partial i} < 0 \tag{56}$$

Becker and Ivashina (2014) provide direct empirical support for this theoretical finding by showing that firms switch from bank loans to corporate bonds following an increase in the nominal policy rate.

6 Optimal Monetary Policy

In this section, I study optimal monetary policy for the period, such as the post-TRACE period, when the liquidity premium channel of monetary policy transmission is dominant in the response of the bond premium to the nominal policy rate. To simplify the presentation, I consider the environment described in Section 2.[19] With the settlement market at the end of each period, maximizing welfare is equivalent to maximizing the per-period welfare that equals the sum of the per-period utility of each agent. The per-period utility of suppliers is 0 due to the CRS technology. The per-period utility of firms that finance investment by borrowing from a bank is $p_L - q_L - r_\ell k$ and their total measure is $1 - \lambda$. The per-period utility of firms that finance investment by issuing corporate bonds is $p_B - q_B - (1-\psi)A$ and their total measure is λ. The per-period utility of banks that lend to a firm is $r_\ell k$ and their total measure is $1 - \lambda$. The per-period utility of consumers is $-(1+\pi)m - \psi a + m + a + T + (1-\lambda)[u(q_L) - p_L] + \lambda[u(q_B) - p_B]$, where $T = \pi m$. The per-period utility of all agents

[19] Discussing optimal monetary policy in the extended environment described in Section 5 requires just a simple relabeling. Notice from (16) and (50) that when a firm has the option of financing both through issuing corporate bonds and borrowing from a bank, such firm will borrow in total from both the corporate bond and the bank loan markets the same amount as the firm that finances only through bank loans. Relabel the fraction of the firms that are borrowing from a bank with or without issuing corporate bonds as $1 - \bar{\lambda}$, instead of $1 - \lambda$. Then, the welfare analysis becomes the exact same as discussed in this section.

sums up to

$$\mathcal{W} \equiv (1-\lambda)[u(q_L) - q_L] + \lambda[u(q_B) - q_B]. \tag{57}$$

A common result in monetary theory is that an increase in the nominal policy rate hurts welfare: a higher nominal policy rate increases the opportunity cost of holding liquidity, induces agents to carry less liquidity, and reduces the quantity of goods they can afford. In this economy, however, the Friedman rule—implementing zero nominal policy rate—is suboptimal. The intuition is as follows. When meeting a firm for trade, agents can meet a firm that financed only by issuing corporate bonds, or a firm that obtained a loan from a bank. Increasing the nominal policy rate has the opposite effects across the two types of meetings. On the one hand, increasing the nominal policy rate makes issuing corporate bonds less expensive and thus helps firms raise more funds and bring a larger amount of intermediate goods to trades in the former type of meeting. More precisely, a higher nominal policy rate increases the price of corporate bonds by increasing their liquidity premium from (30); the higher price of corporate bonds makes issuing corporate bonds cheaper, allowing firms to raise more funds from (21); and firms can produce more goods in trades by bringing a larger amount of intermediate goods from (29) or (31). On the other hand, increasing the nominal policy rate increases the cost of holding money and makes consumers carry less liquidity, which in turn makes firms borrow less from banks due to the lower demand and hurts the latter type of meeting. More precisely, a higher nominal policy rate reduces the real amount of liquidity that consumers carry with themselves for trades from (26); due to the lower demand, firms will borrow less from banks from (16); and a smaller amount of goods are produced from (34). Consider that the nominal policy rate is currently low so that the borrowing cost in the corporate bond market is high and a relatively small amount of goods are produced in the former type of meeting, while the borrowing cost in the bank loan market is low and already a large amount of goods are produced in the latter type of meeting. In such case, the welfare loss from the latter type of meeting is only second order, while the welfare gain from the former type of meeting becomes first order. More precisely, in $\partial\mathcal{W}/\partial i = (1-\lambda)\cdot\partial(u(q_L) - q_L)/\partial i + \lambda\cdot\partial(u(q_B) - q_B)/\partial i$, the first term represents

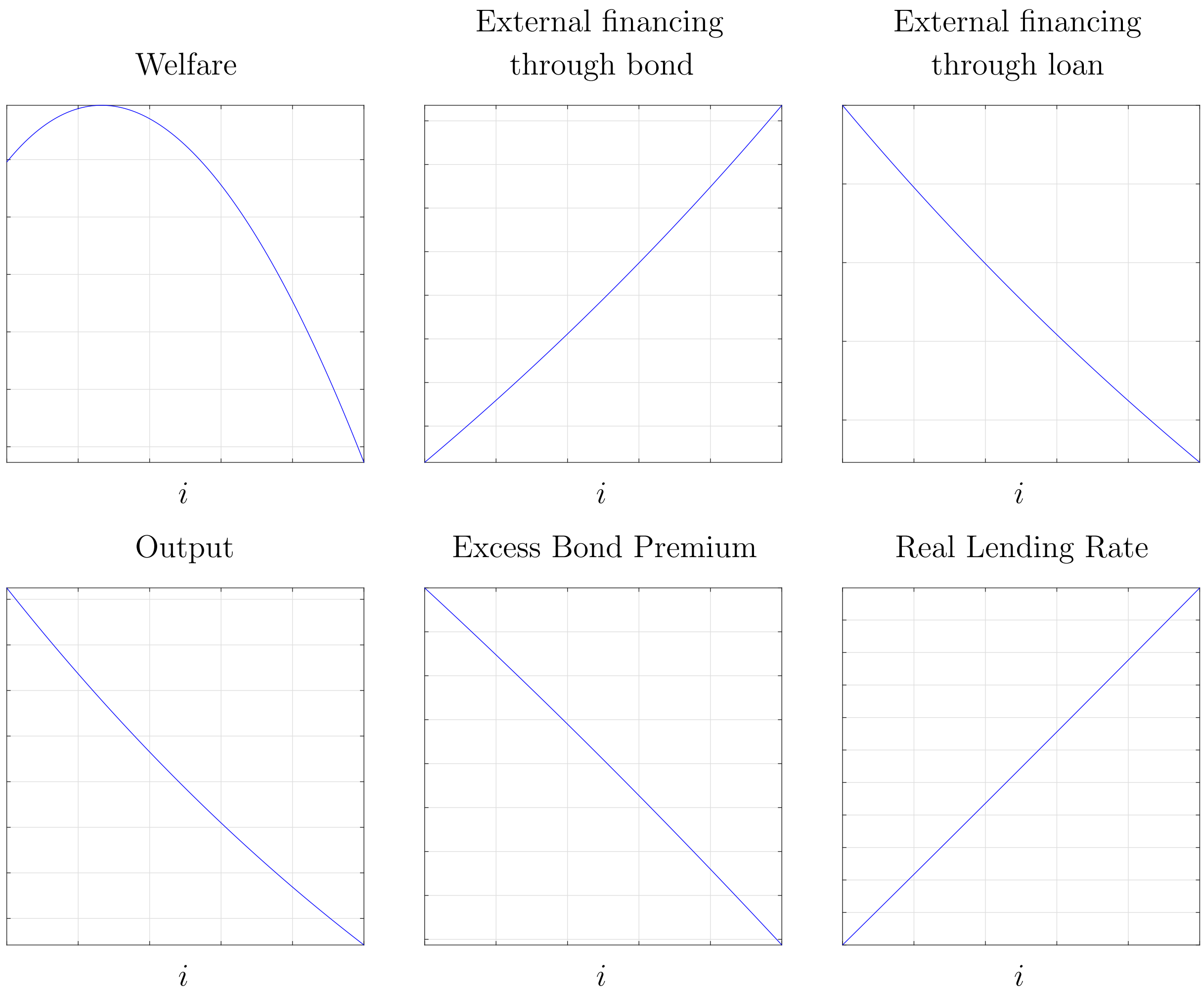

Figure 7. Effect of monetary policy on the aggregate outcomes

the welfare loss from the latter type of meeting, and the second term represents the welfare gain from the former type of meeting because $\partial(u(q_L) - q_L)/\partial i < 0$ since $\partial q_L/\partial i < 0$ and because $\partial(u(q_B) - q_B)/\partial i > 0$ since $\partial q_B/\partial i > 0$. However, at the Friedman rule, when $i \to 0$, $\partial(u(q_L) - q_L)/\partial i \to 0$ because $q_L \to q^*$ as $i \to 0$ and $u'(q^*) = 1$. Therefore, when $i \to 0$, $\partial \mathcal{W}/\partial i = \lambda \cdot \partial(u(q_B) - q_B)/\partial i > 0$. That is, at the Friedman rule, increasing the nominal policy rate can be welfare improving. The following proposition summarizes the discussion.

Proposition 3. *A deviation from the Friedman rule is optimal, i.e., the optimal monetary policy requires* $i > 0$.

Figure 7 shows the relationship between the nominal policy rate and the welfare of the economy, along with other aggregate variables. The main force that drives a positive nominal policy rate to be optimal is the liquidity premium channel of monetary policy. Therefore,

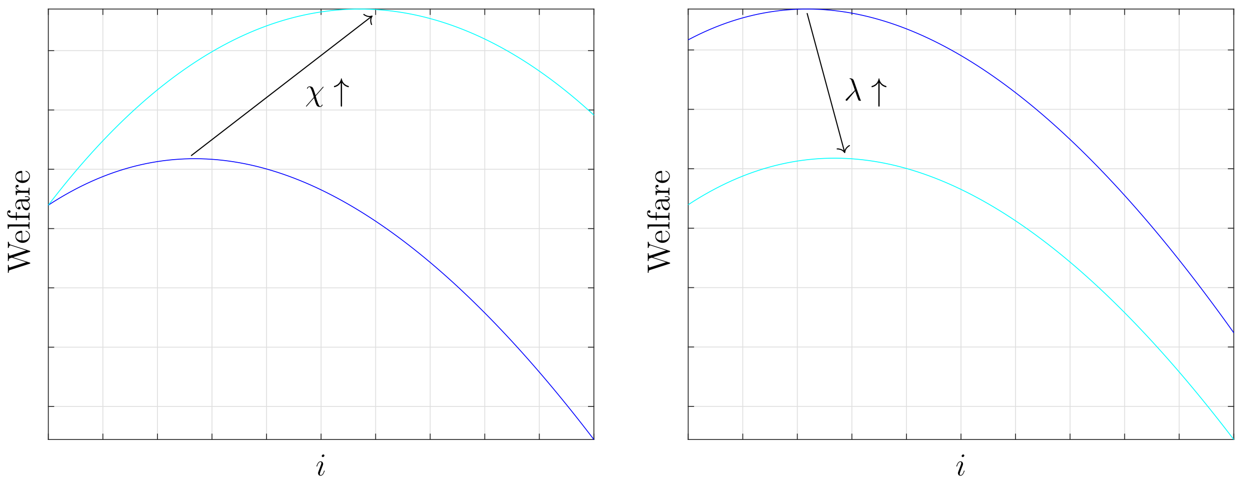

Figure 8. The corporate bond secondary market liquidity and the distribution of firms along their ways of financing matters for the optimal policy rate.

the stronger the channel, the higher the optimal policy rate. Figure 8 provides numerical examples that support this argument. In particular, the optimal nominal policy rate depends on the corporate bond secondary market liquidity and the distribution of firms along their ways of financing. The more liquid the corporate bond secondary market, or the more firms financing through issuing corporate bonds, the higher the optimal policy rate.

7 Conclusion

Central banks influence firms' investment through controlling the nominal policy rate, which then gets transmitted to the real rates at which firms borrow. I study this transmission mechanism in a general equilibrium macroeconomic model where firms have two options for external financing: they can issue corporate bonds or obtain bank loans. A theoretical novelty of my model is that corporate bonds are not just stores of value but also serve a liquidity role. The model delivers three predictions. First, an increase in the nominal policy rate can lower the borrowing cost in the corporate bond market, while increasing that in the bank loan market. This is in sharp contrast with the common belief that all rates in the economy move in the same direction in response to changes in monetary policy. I highlight the role of asset liquidity in this result and provide empirical evidence. Second, a higher nominal policy rate induces firms to substitute corporate bonds for bank loans, and this result is supported by the existing empirical evidence. Third, the Friedman rule is suboptimal so that keeping the cost of holding liquidity at a positive level is socially optimal. The optimal policy rate is an increasing function of the degree of corporate bond liquidity.

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Online Appendices

for

"Liquidity Premium, Credit Costs, and Optimal Monetary Policy"

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A Theory Appendix

A.1 Full Characterization of the Equilibrium

This section characterizes the equilibrium beyond the parameter space in Assumption 1. First start with the optimal behavior of a firm that finances investment by issuing corporate bonds. From (10), at a given price ψ, the firm chooses the amount of corporate bonds to issue, $A \geq 0$, that maximizes $(p_B - q_B) - (1-\psi)A$, which, using (12) and (13), reduces to $(1-\theta)(u(q_B) - q_B) - (1-\psi)A$, where $q_B = \min\{v^{-1}(\tilde{m} + \chi\tilde{a}), \psi A\}$ when believing that a consumer will carry $\tilde{m}$ amount of real balances and $\tilde{a}$ amount of corporate bonds to the DM. An equilibrium exists when $1 - \psi > 0$, or $\psi < 1$, that is, when borrowing through the corporate bond market is costly. Assumption 2, given below, guarantees that this is the case. Since the firm will not want to bring more capital to the DM than it needs to produce the amount of the DM goods that a consumer can afford, $v^{-1}(\tilde{m} + \chi\tilde{a})$, and the maximization problem becomes

$$\max_{0 \leq A \leq v^{-1}(\tilde{m}+\chi\tilde{a})/\psi} \{(1-\theta)(u(\psi A) - \psi A) - (1-\psi)A\}. \tag{58}$$

The solution describes the optimal corporate bond issuance decision of the firm, or the supply of corporate bonds, and is given by

$$A = \min\{v^{-1}(\tilde{m} + \chi\tilde{a})/\psi, \bar{A}\} \tag{59}$$

where $\bar{A}$ solves

$$\frac{1}{\psi} - 1 = (1-\theta)(u'(\psi\bar{A}) - 1). \tag{60}$$

Now consider the optimal behavior of a consumer who chooses a portfolio of real balances and corporate bonds. From (2), the consumer chooses the amount of real balances, m, and the amount of corporate bonds, a, that maximize $-(1+\pi)m - \psi a + \beta V^C(m, a)$, which, using

(4) and the linearity of W^C, becomes

$$\max_{m\geq 0,a\geq 0}\Big\{-(1+\pi)m-\psi a+\beta m+\beta a+\beta(1-\lambda)[u(q_L)-p_L]+\beta\lambda[u(q_B)-p_B]\Big\}. \tag{61}$$

When believing that a firm that issues corporate bonds will issue $\tilde{A}$ amount of corporate bonds and bring $\psi\tilde{A}$ amount of capital to the DM and that a firm that borrows from a bank will bring $\tilde{k}$ amount of capital to the DM, $q_L=\min\{v^{-1}(m+\chi a),\tilde{k}\}$ and $q_B=\min\{v^{-1}(m+\chi a),\psi\tilde{A}\}$. Depending on the relative size of $\tilde{k}$, $\psi\tilde{A}$ and $v^{-1}(m+\chi a)$, the maximization problem is:

For $m+\chi a\leq\min\{v(\tilde{k}),v(\psi\tilde{A})\}$,

$$\max_{m\geq 0,a\geq 0}\Big\{-(1+\pi)m-\psi a+\beta m+\beta a+\beta\big[u(v^{-1}(m+\chi a))-v(v^{-1}(m+\chi a))\big]\Big\}, \tag{62}$$

for $\min\{v(\tilde{k}),v(\psi\tilde{A})\}<m+\chi a\leq\max\{v(\tilde{k}),v(\psi\tilde{A})\}$, if $\psi\tilde{A}<\tilde{k}$,

$$\max_{m\geq 0,a\geq 0}\Big\{-(1+\pi)m-\psi a+\beta m+\beta a+\beta(1-\lambda)\big[u(v^{-1}(m+\chi a))-v(v^{-1}(m+\chi a))\big]\Big\}, \tag{63}$$

and if $\tilde{k}<\psi\tilde{A}$,

$$\max_{m\geq 0,a\geq 0}\Big\{-(1+\pi)m-\psi a+\beta m+\beta a+\beta\lambda\big[u(v^{-1}(m+\chi a))-v(v^{-1}(m+\chi a))\big]\Big\}, \tag{64}$$

and for $\max\{v(\tilde{k}),v(\psi\tilde{A})\}<m+\chi a$,

$$\max_{m\geq 0,a\geq 0}\Big\{-(1+\pi)m-\psi a+\beta m+\beta a\Big\}. \tag{65}$$

I consider an equilibrium where expectations are rational. (64) is not a relevant case with $\psi\tilde{A}<\tilde{k}$ from (16) and (59), and (65) does not have a solution. The solution describes the optimal portfolio choice of real balances and corporate bonds of the consumer, or the demand for real balances and corporate bonds. The solution to (63) satisfies

$$m+\chi a=\max\{v(\psi\tilde{A}),\bar{m}+\chi\bar{a}\} \tag{66}$$

where $\bar{m} + \chi\bar{a}$ solves

$$1 + \pi = \beta \left\{ 1 + (1 - \lambda) \left(\frac{u'(v^{-1}(\bar{m} + \chi\bar{a}))}{v'(v^{-1}(\bar{m} + \chi\bar{a}))} - 1 \right) \right\}, \tag{67}$$

which simplify to

$$i = (1 - \lambda) L(\bar{m} + \chi\bar{a}), \tag{68}$$

where $i \equiv (1 + \pi)/\beta - 1$ and $L(\cdot) \equiv u'(v^{-1}(\cdot))/v'(v^{-1}(\cdot)) - 1$ with $L'(\cdot) < 0$. The solution to (62) satisfies

$$m + \chi a = \min\{v(\psi\tilde{A}), \bar{\bar{m}} + \chi\bar{\bar{a}}\} \tag{69}$$

where $\bar{\bar{m}} + \chi\bar{\bar{a}}$ solves

$$1 + \pi = \beta \left\{ 1 + \left(\frac{u'(v^{-1}(\bar{\bar{m}} + \chi\bar{\bar{a}}))}{v'(v^{-1}(\bar{\bar{m}} + \chi\bar{\bar{a}}))} - 1 \right) \right\}, \tag{70}$$

which simplify to

$$i = L(\bar{\bar{m}} + \chi\bar{\bar{a}}). \tag{71}$$

For both cases, the price of corporate bonds is given by

$$\psi = \beta(1 + \chi i). \tag{72}$$

Note that $\bar{m} + \chi\bar{a}$ is the amount of liquidity consumers would decide to bring to the DM when their liquidity position will be on the shorter side of the bargaining only if they trade with a firm that borrows from a bank, and that $\bar{\bar{m}} + \chi\bar{\bar{a}}$ is the amount of liquidity consumers would decide to bring to the DM when their liquidity position will always be on the shorter side of the bargaining whether a firm they meet finances investment by borrowing from a bank or by issuing corporate bonds. By comparing (68) and (71), we see that $\bar{m} + \chi\bar{a} < \bar{\bar{m}} + \chi\bar{\bar{a}}$. There are three cases depending on the relative size of $v(\psi\bar{A})$, $\bar{m} + \chi\bar{a}$ and $\bar{\bar{m}} + \chi\bar{\bar{a}}$ given i.

Define $\bar{\imath}$ and $\bar{\bar{\imath}}$ as follows:

$$\bar{\imath} \equiv \frac{(1-\lambda)(1-\beta)\theta}{1-\theta+(1-\lambda)\beta\theta\chi}, \tag{73}$$

$$\bar{\bar{\imath}} \equiv \frac{(1-\beta)\theta}{1-\theta+\beta\theta\chi}. \tag{74}$$

The first is when $i \leq \bar{\imath}$ and $v(\psi \bar{A}) \leq \bar{m} + \chi\bar{a} < \bar{\bar{m}} + \chi\bar{\bar{a}}$. This is when the price of the corporate bonds is not high enough for firms to finance investment enough to fully satisfy the consumer's demand, $\bar{m} + \chi\bar{a}$. Hence, the firms that are borrowing from a bank and thus can satisfy the consumer's demand are at the margin of the consumer's decision on how much liquidity to bring to the DM. The second is when $\bar{\imath} < i \leq \bar{\bar{\imath}}$ and $\bar{m} + \chi\bar{a} < v(\psi\bar{A}) \leq \bar{\bar{m}} + \chi\bar{\bar{a}}$. This is when the price of the corporate bonds is high enough for firms to finance investment enough to satisfy $\bar{m} + \chi\bar{a}$, but not high enough to satisfy $\bar{\bar{m}} + \chi\bar{\bar{a}}$. When this is the case, a consumer will bring liquidity just enough to be able to purchase $\psi\bar{A}$ amount of the DM goods, and such amount of liquidity will make the consumer on the shorter side of the bargaining with both the firms that are borrowing from a bank and the firms that are issuing corporate bonds. The third case is when $\bar{\bar{\imath}} < i$ and $\bar{m} + \chi\bar{a} < \bar{\bar{m}} + \chi\bar{\bar{a}} \leq v(\psi\bar{A})$, that is, when the price of the corporate bonds is high enough to satisfy $\bar{\bar{m}} + \chi\bar{\bar{a}}$. In this case, a consumer will decide the amount of liquidity to bring to the DM with considering both the firms that are borrowing from a bank and the firms that are issuing corporate bonds at the same margin. The firms with access to the corporate bond market will issue corporate bonds just enough to satisfy $\bar{\bar{m}} + \chi\bar{\bar{a}}$.[20]

Now I specify the assumption that ensures $\psi < 1$ so that borrowing through the corporate bond market is costly.

Assumption 2. $i < \dfrac{1-\beta}{\beta\chi}$.

The equilibrium is defined as below.

Definition 2. *A steady state equilibrium of the economy corresponds to a constant sequence* $(q_L, q_B, m, a, A, \psi, k, r_\ell)$*, where* q_L *is the DM goods traded between a consumer and a firm that*

[20]For each given i, there are more equilibria other than those described above. The most trivial one is when no one brings any thinking that everyone else will bring nothing. Although this belief can be consistent in equilibrium, however, such equilibrium is not Pareto efficient. In this paper, I consider the Pareto efficient equilibrium for each i.

finances investment by borrowing from a bank, q_B is the DM goods traded between a consumer and a firm that finances investment by issuing corporate bonds, m is the consumer's real balance holdings, a is the consumer's corporate bond holdings, A is the supply of corporate bonds issued by firms, ψ is the price of corporate bonds, k is the size of a loan that a bank lends to a firm, and r_ℓ is the real lending rate of loans. Under Assumption 2, (q_L, q_B) satisfy:

For $i \leq \bar{\iota}$,

$$q_L = v^{-1}\left(L^{-1}\left(\frac{i}{1-\lambda}\right)\right), \tag{75}$$

$$q_B = (u')^{-1}\left(\frac{1-\beta(1+\chi i)}{\beta(1+\chi i)(1-\theta)} + 1\right), \tag{76}$$

for $\bar{\iota} < i \leq \bar{\bar{\iota}}$,

$$q_L = q_B = (u')^{-1}\left(\frac{1-\beta(1+\chi i)}{\beta(1+\chi i)(1-\theta)} + 1\right), \tag{77}$$

and for $\bar{\bar{\iota}} < i$,

$$q_L = q_B = v^{-1}(L^{-1}(i)). \tag{78}$$

(m, a, A, ψ) satisfy

$$\psi = \beta(1+\chi i), \tag{79}$$

$$A = q_B/\psi, \tag{80}$$

$$a = \lambda A, \tag{81}$$

$$m = v(q_L) - \chi a, \tag{82}$$

and (k, r_ℓ) satisfy

$$k = q_L = v^{-1}(m + \chi a), \tag{83}$$

$$r_\ell = \frac{\eta(1-\theta)(u(k)-k)}{k}, \tag{84}$$

where

$$v(\cdot) = (1-\theta)u(\cdot) + \theta\,\cdot\,, \quad v'(\cdot) > 0, \tag{85}$$

$$L(\cdot) = u'(v^{-1}(\cdot))/v'(v^{-1}(\cdot)) - 1, \quad L'(\cdot) < 0. \tag{86}$$

A.1.1 Optimal Monetary Policy

Among $i \leq \bar{\iota}$, the welfare-maximizing nominal policy rate depends on the relative size of $(1-\lambda)\cdot\partial(u(q_L)-q_L)/\partial i < 0$ and $\lambda\cdot\partial(u(q_B)-q_B)/\partial i > 0$. When neither λ nor χ is large, the latter force is not so large that the welfare-maximizing policy rate satisfying $\partial\mathcal{W}/\partial i = 0$ exists in the interior. When either λ or χ is large, the latter force becomes so large that the welfare-maximizing policy rate exists on the right boundary at $i = \bar{\iota}$. In addition, note that when $\bar{\iota} < i \leq \bar{\bar{\iota}}$, $\partial\mathcal{W}/\partial i > 0$ as can be seen from (77), that when $\bar{\bar{\iota}} \leq i$, $\partial\mathcal{W}/\partial i < 0$ as can be seen from (78), and therefore that among $i > \bar{\iota}$, $i = \bar{\bar{\iota}}$ maximizes the welfare. These together imply that when neither λ nor χ is large, there will be a welfare-maximizing policy rate that is less than $\bar{\iota}$, and that when either λ or χ is large, the welfare-maximizing policy rate will be $\bar{\bar{\iota}}$. Figures A1 and A2 illustrate these observations. Figures A3 (for small λ and small χ), A4 (for large λ and small χ) and A5 (for small λ and large χ) show the effect of the nominal policy rate on different variables, including the welfare, the amount of external financing through bonds and loan, the real balance, the excess bond premium, the real lending rate, and the average output. In all figures, there are two kinks, and the first and the second correspond to $i = \bar{\iota}$ and $i = \bar{\bar{\iota}}$, respectively. Exceptions are the figures for the amount of external financing through issuing corporate bonds that display one kink, which corresponds to $i = \bar{\bar{\iota}}$ as can be seen from (76), (77) and (78). In all figures, we can see that the Friedman rule when $i \to 0$ is not optimal. Also, notice that the relationship between the welfare and the average output is not monotone, due to the heterogeneity in the effect of the nominal policy rate across the firms using different financing sources. Figure A6 illustrates this point.

A.2 Loan Contract with a Different Timing of Events

There are two types of meetings in the OTC market for loans in the second subperiod: one between a bank and a firm that does not have access to the corporate bond market, and the other between a bank and a firm that has access to the corporate bond market and could issue corporate bonds to finance investment in addition to obtaining a loan from a bank. The bargaining problem in the former meeting is the same as in the previous environment, and the solution is given by (16) and (17).

In the latter meeting, a bank and a firm bargain over the terms of a loan contract, (k^B, r_ℓ^B). As before, I restrict attention to the case in which the firm's capacity is on the shorter side of the bargaining in the DM if the firm finances investment solely by issuing corporate bonds. Define $\bar{A}$ that solves (20) at given ψ:

$$\bar{A} \equiv (u')^{-1}\left(\frac{1-\psi}{\psi(1-\theta)}+1\right)\Big/\psi. \tag{87}$$

If a firm borrows more than $\psi\bar{A}$ from a bank, the firm will have no incentive to issue corporate bonds to raise more numeraire. On the other hand, if a firm borrows less than $\psi\bar{A}$ from a bank, the firm will issue A amount of corporate bonds so that it raises in total $\psi\bar{A} = \psi A + k^B$ amount of numeraire.

First consider the latter case in which a firm borrows less than $\psi\bar{A}$ from a bank and will issue A amount of corporate bonds so that it raises in total $\psi\bar{A} = \psi A + k^B$ amount of numeraire. The firm's continuation value with a loan contract is $\beta V^F(\psi A + k^B, A + (1 + r_\ell^B)k^B)$, where $A = (\psi\bar{A} - k^B)/\psi$ so that $\psi A + k^B = \psi\bar{A}$. The firm's outside option is to issue corporate bonds. When the firm could not borrow from a bank, it will issue $\bar{A}$ amount of corporate bonds, and the firm's continuation value without a loan contract will be $\beta V^F(\psi\bar{A}, \bar{A})$. Thus, the firm's surplus is $\beta[V^F(\psi\bar{A}, A+(1+r_\ell^B)k^B) - V^F(\psi\bar{A}, \bar{A})]$, which, using (47), reduces to $\beta[(1-\psi)(\bar{A} - A) - r_\ell^B k^B]$. As before, the bank's surplus is $\beta r_\ell^B k^B$. The terms of a loan contract specify (k^B, r_ℓ^B) that solve

$$\max_{k^B \le \psi\bar{A}, r_\ell^B} \left[(1-\psi)(\bar{A} - A) - r_\ell^B k^B\right]^{1-\eta} \left[r_\ell^B k^B\right]^{\eta}. \tag{88}$$

Using $A = (\psi\bar{A} - k^B)/\psi$, the bargaining problem becomes

$$\max_{k^B \le \psi\bar{A}, r_\ell^B} \left[((1-\psi)/\psi - r_\ell^B)k^B\right]^{1-\eta} \left[r_\ell^B k^B\right]^\eta. \tag{89}$$

The solution k^B maximizes the total surplus, $((1-\psi)/\psi)k^B$, subject to $k^B \le \psi\bar{A}$. Under Assumption 1, $\psi < 1$ and $k^B = \psi\bar{A}$, which means the former case is the relevant one.

Now consider the former case in which a firm borrows more than $\psi\bar{A}$ from a bank and has no further incentive to issue corporate bonds. The firm's continuation value with a loan contract is $\beta V^F(k^B, (1+r_\ell^B)k^B)$. The firm's continuation value of issuing corporate bonds without a loan contract is $\beta V^F(\psi\bar{A}, \bar{A})$. Thus, the firm's surplus is $\beta[V^F(k^B, (1+r_\ell^B)k^B) - V^F(\psi\bar{A}, \bar{A})]$, which, using (12), (13) and (47), reduces to $\beta[(1-\theta)(u(k^B) - k^B) - r_\ell^B k^B - (1-\theta)(u(\psi\bar{A}) - \psi\bar{A}) + (1-\psi)\bar{A}]$. As before, the bank's surplus is $\beta r_\ell^B k^B$. The terms of a loan contract specify (k^B, r_ℓ^B) that solve

$$\max_{\psi\bar{A} \le k^B \le v^{-1}(\tilde{m}+\chi\tilde{a}), r_\ell^B} \left[(1-\theta)(u(k^B) - k^B) - r_\ell^B k^B - (1-\theta)(u(\psi\bar{A}) - \psi\bar{A}) + (1-\psi)\bar{A}\right]^{1-\eta} \left[r_\ell^B k^B\right]^\eta,$$

where $v^{-1}(\tilde{m}+\chi\tilde{a})$ is the amount of the DM goods that a consumer can afford when believing that a consumer will carry $\tilde{m}$ amount of real balances and $\tilde{a}$ amount of corporate bonds to the DM, and a firm will not want to borrow more than it needs to produce $v^{-1}(\tilde{m}+\chi\tilde{a})$ amount of the DM goods. The solution is such that k^B maximizes the total surplus, $(1-\theta)(u(k^B) - k^B) - (1-\theta)(u(\psi\bar{A}) - \psi\bar{A}) + (1-\psi)\bar{A}$, subject to $\psi\bar{A} \le k^B \le v^{-1}(\tilde{m}+\chi\tilde{a})$ and thus the solution is as in (16). Therefore, both the firm that has an outside option in bargaining and the firm that does not will borrow the same amount of loan from a bank.

The real lending rate, however, will be different between the firm that has an outside option in bargaining and the firm that does not. The real lending rate for the firm that does not have access to the corporate bond market is given by (17). On the other hand, the real lending rate for the firm that has access to the corporate bond market is

$$r_\ell^B = \frac{\eta[(1-\theta)(u(k^B) - k^B) - (1-\theta)(u(\psi\bar{A}) - \psi\bar{A}) + (1-\psi)\bar{A}]}{k^B}, \tag{90}$$

where k^B is given by (16).

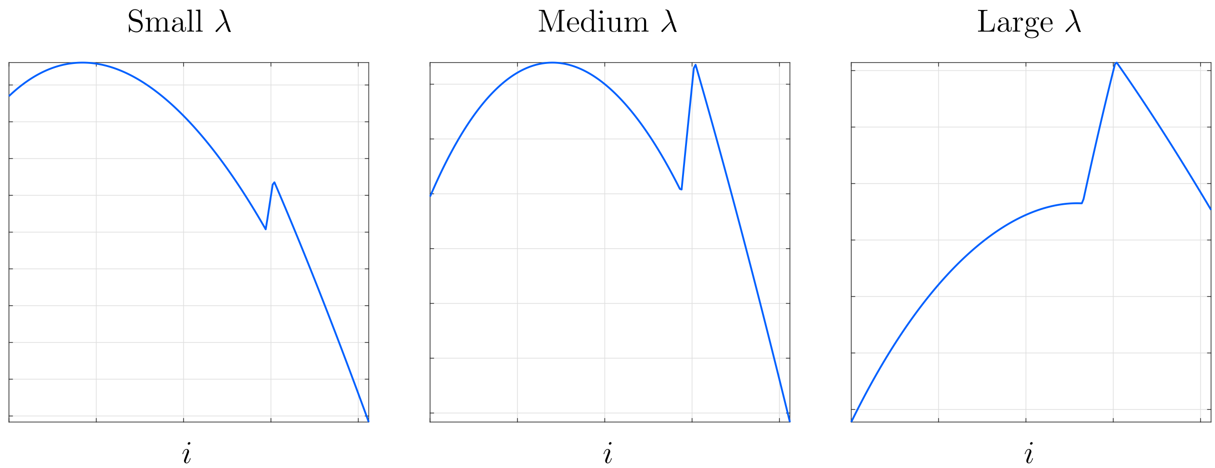

Figure A1. Effect of monetary policy on the welfare of the economy for different values of λ. Parameter values: Log utility; $\beta = 0.97$; $\lambda = 0.1$ (left), 0.165 (middle), 0.35 (right); $\chi = 0.15$; $\eta = 0.8$; $\theta = 0.95$.

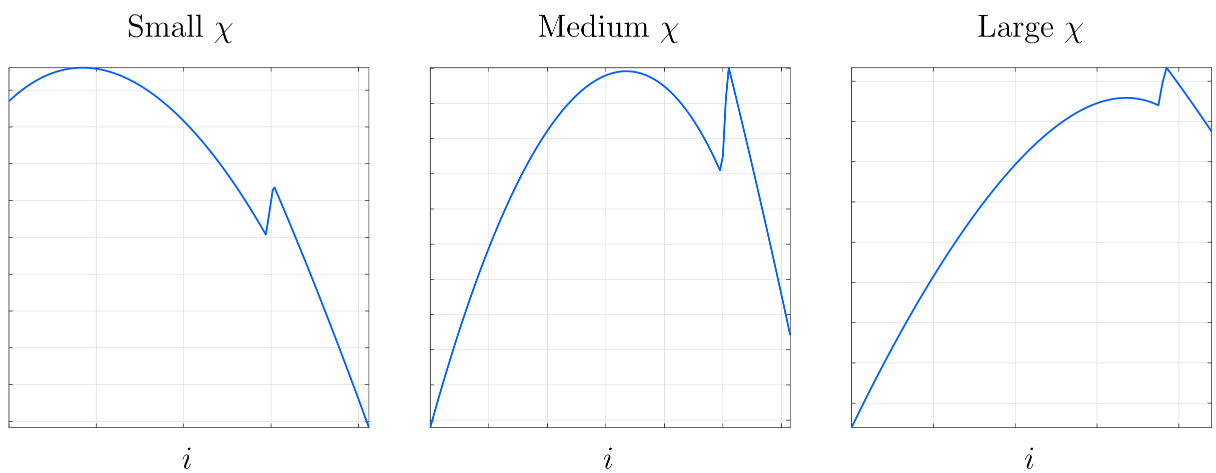

Figure A2. Effect of monetary policy on the welfare of the economy for different values of χ. Parameter values: Log utility; $\beta = 0.97$; $\lambda = 0.1$; $\chi = 0.15$ (left), 0.25 (middle), 0.35 (right); $\eta = 0.8$; $\theta = 0.95$.

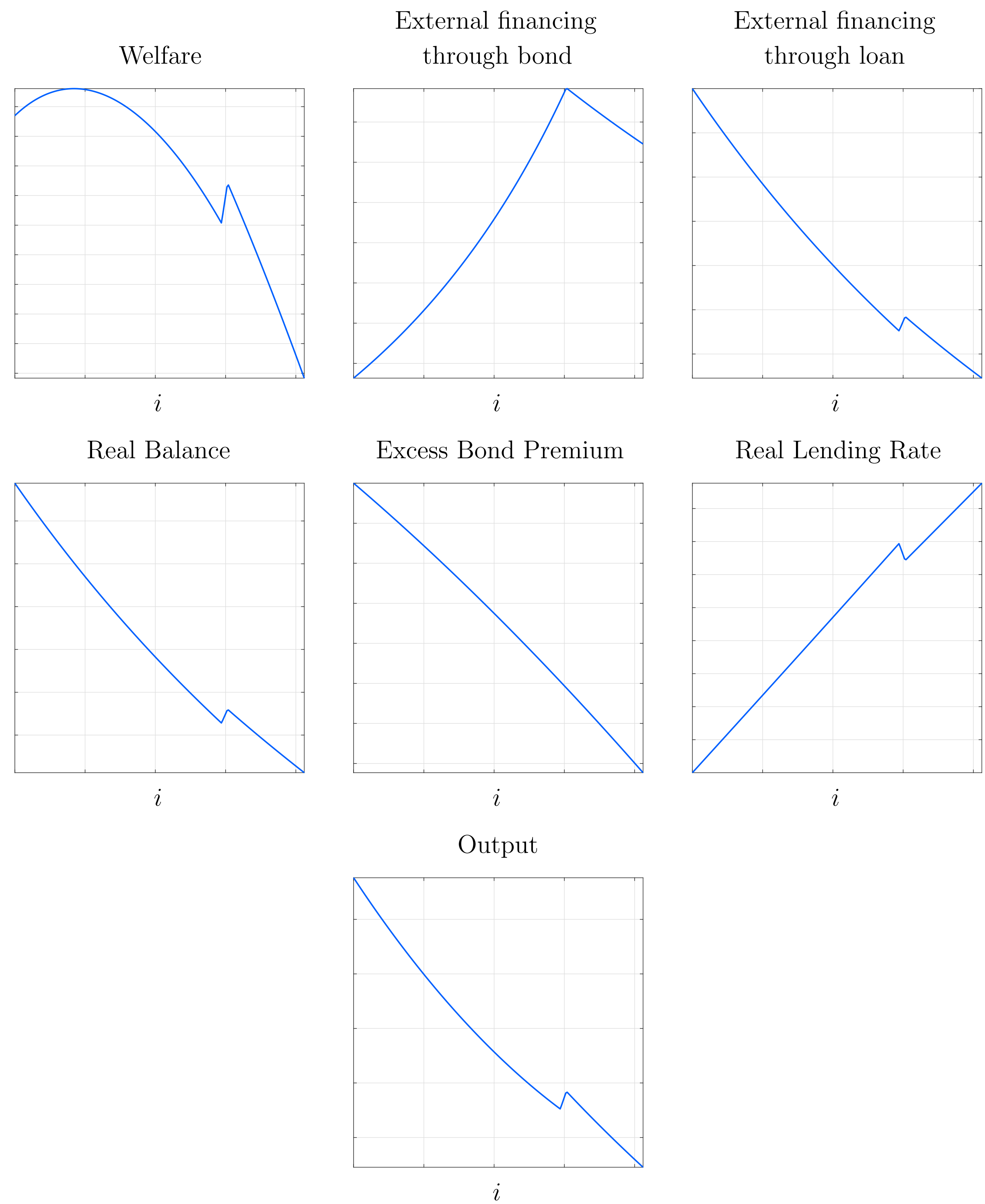

Figure A3. Effect of monetary policy, when the fraction of the firms with access to the corporate bond market is small (small λ) and the corporate bond secondary market is not so liquid (small χ). Parameter values: Log utility; $\beta = 0.97$; $\lambda = 0.1$; $\chi = 0.15$; $\eta = 0.8$; $\theta = 0.95$.

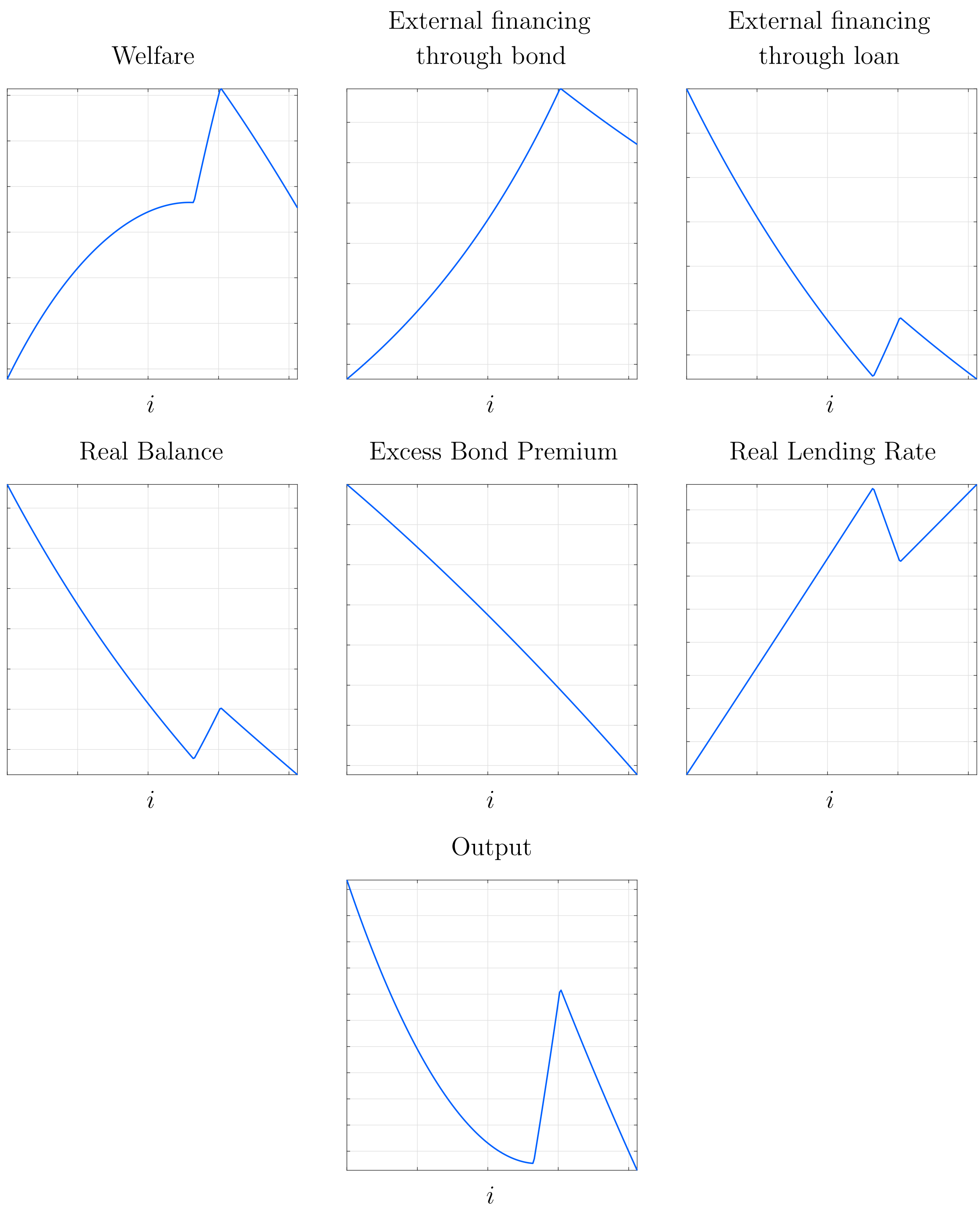

Figure A4. Effect of monetary policy, when the fraction of the firms with access to the corporate bond market is large (large λ) and the corporate bond secondary market is not so liquid (small χ). Parameter values: Log utility; $\beta = 0.97$; $\lambda = 0.35$; $\chi = 0.15$; $\eta = 0.8$; $\theta = 0.95$.

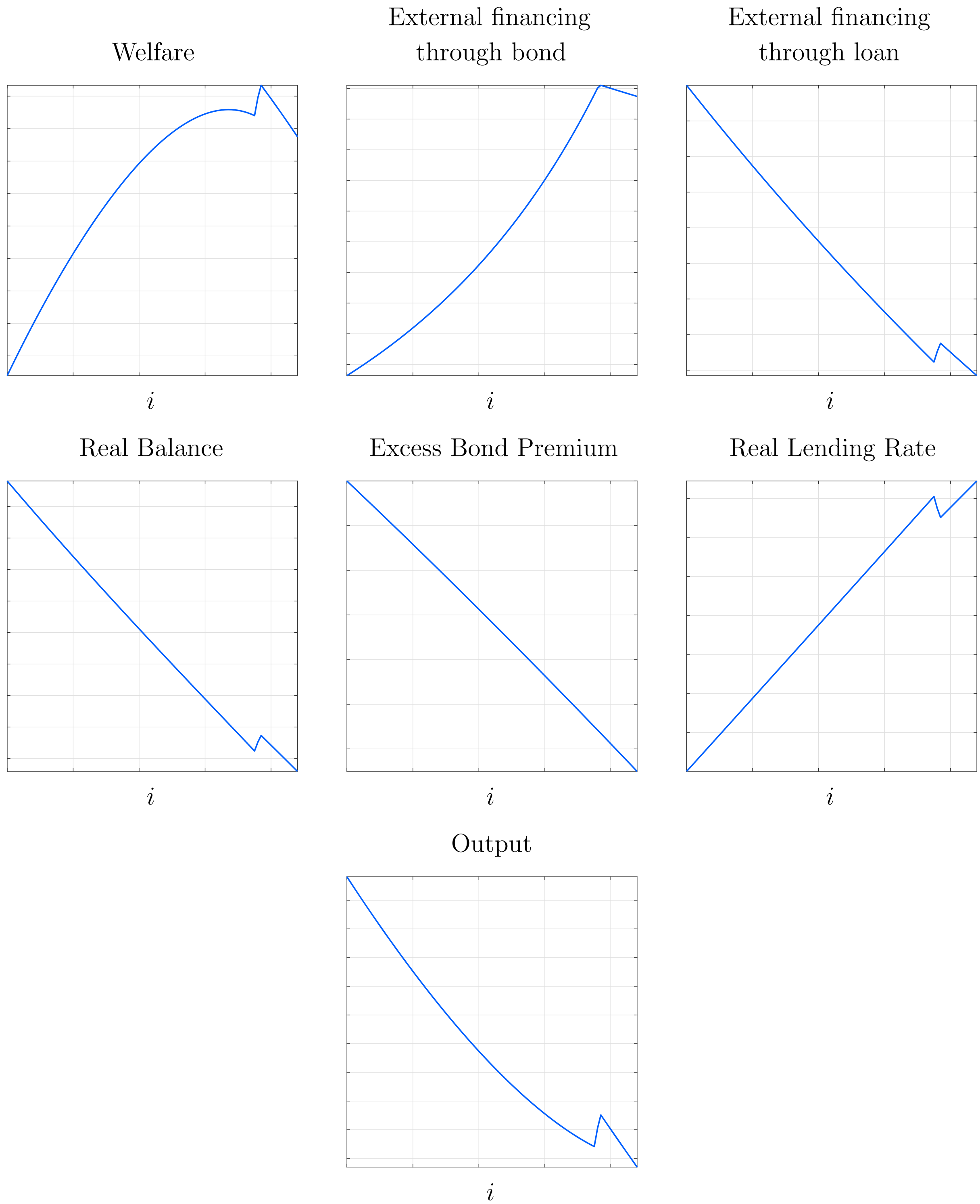

Figure A5. Effect of monetary policy, when the fraction of the firms with access to the corporate bond market is small (small λ) and the corporate bond secondary market is highly liquid (large χ). Parameter values: Log utility; $\beta = 0.97$; $\lambda = 0.1$; $\chi = 0.35$; $\eta = 0.8$; $\theta = 0.95$.

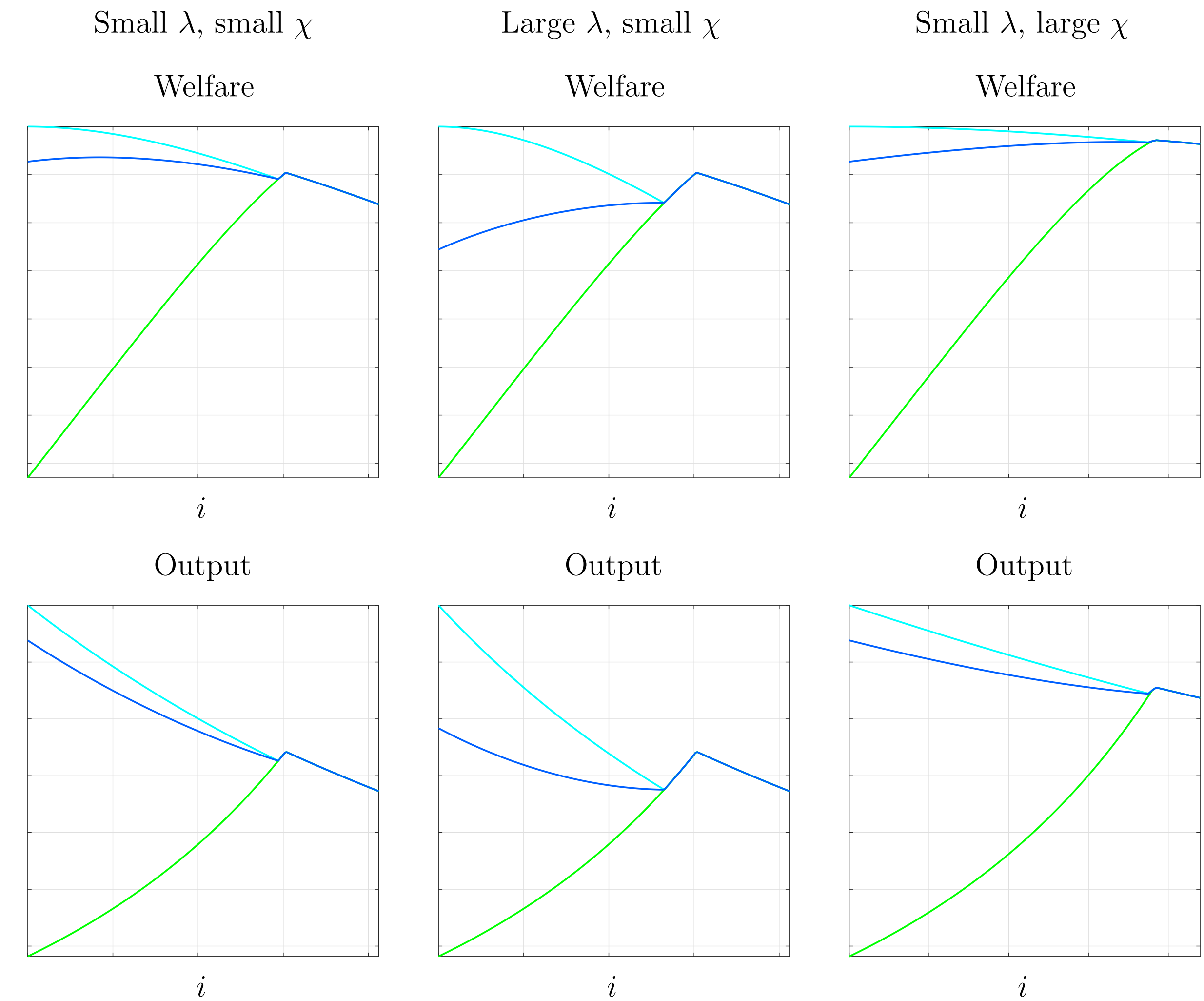

Figure A6. Effect of monetary policy on the welfare and the output of the economy for small λ (the fraction of the firms with access to the corporate bond market) and small χ (the liquidity of the corporate bond secondary market) (left), large λ and small χ (middle), and small λ and large χ (right). For each figure for the welfare, the top line (in bright blue) plots $u(q_L) - q_L$, the bottom line (in bright green) plots $u(q_B) - q_B$, and the middle line (in blue) plots $(1-\lambda)[u(q_L) - q_L] + \lambda[u(q_B) - q_B]$. For each figure for the output, the top line (in bright blue) plots q_L, the bottom line (in bright green) plots q_B, and the middle line (in blue) plots $(1-\lambda)q_L + \lambda q_B$. For the parameter values used, refer to the notes in Figure A3 for small λ and small χ, Figure A4 for large λ and small χ, and Figure A5 for small λ and large χ.

B Appendix for Empirical Analysis

B.1 Data

For the macro time-series data, I use data from the Federal Reserve Economic Data (FRED) from the Federal Reserve Bank of St. Louis. The 1-year and the 2-year policy rates are the 1-Year and the 2-year Treasury Constant Maturity Rates (FRED series `GS1` and `GS2`). Industrial production is Industrial Production Index (FRED series `INDPRO`). Consumer Price Index is Consumer Price Index for All Urban Consumers: All Items in U.S. City Average (FRED series `CPIAUCSL`). The expected inflation rate is the 5-Year Forward Inflation Expectation Rate (FRED series `T5YIFRM`). The excess bond premium is constructed by Gilchrist and Zakrajšek (2012) and keeps updated by Favara, Gilchrist, Lewis, and Zakrajšek at https://www.federalreserve.gov/econresdata/notes/feds-notes/2016/files/ebp_csv.csv. Monetary policy shocks are the high-frequency identified surprises from Federal Funds futures around the Federal Open Market Committee policy announcements constructed by Gertler and Karadi (2015), and the series updated until 2016:12 is from Jarociński and Karadi (2020).

B.2 Additional Figures

Figure A7 replicates Gertler and Karadi (2015) with unit effect normalization. Figures B1–B14 are for sensitivity analysis. Figures C1–C18 show the responses of all variables, not only the variables of main focus (the excess bond premium (EBP), the bid-ask spreads, the trading volume, and the real bank loan rate), to a one-percent increase in the nominal policy rate for all different specifications. For quick references, refer to the following table:

Sample Period	Entire Period	Pre-TRACE Period	Post-TRACE Period			
Variable of focus	EBP	EBP	EBP	Bid-Ask Spreads	Trading Volume	Loan Rate
LP-IV	C1	C2	C3	C10	C13	C16
FALP-IV	C4	C5	C6	C11	C14	C17
SVAR-IV	C7	C8	C9	C12	C15	C18

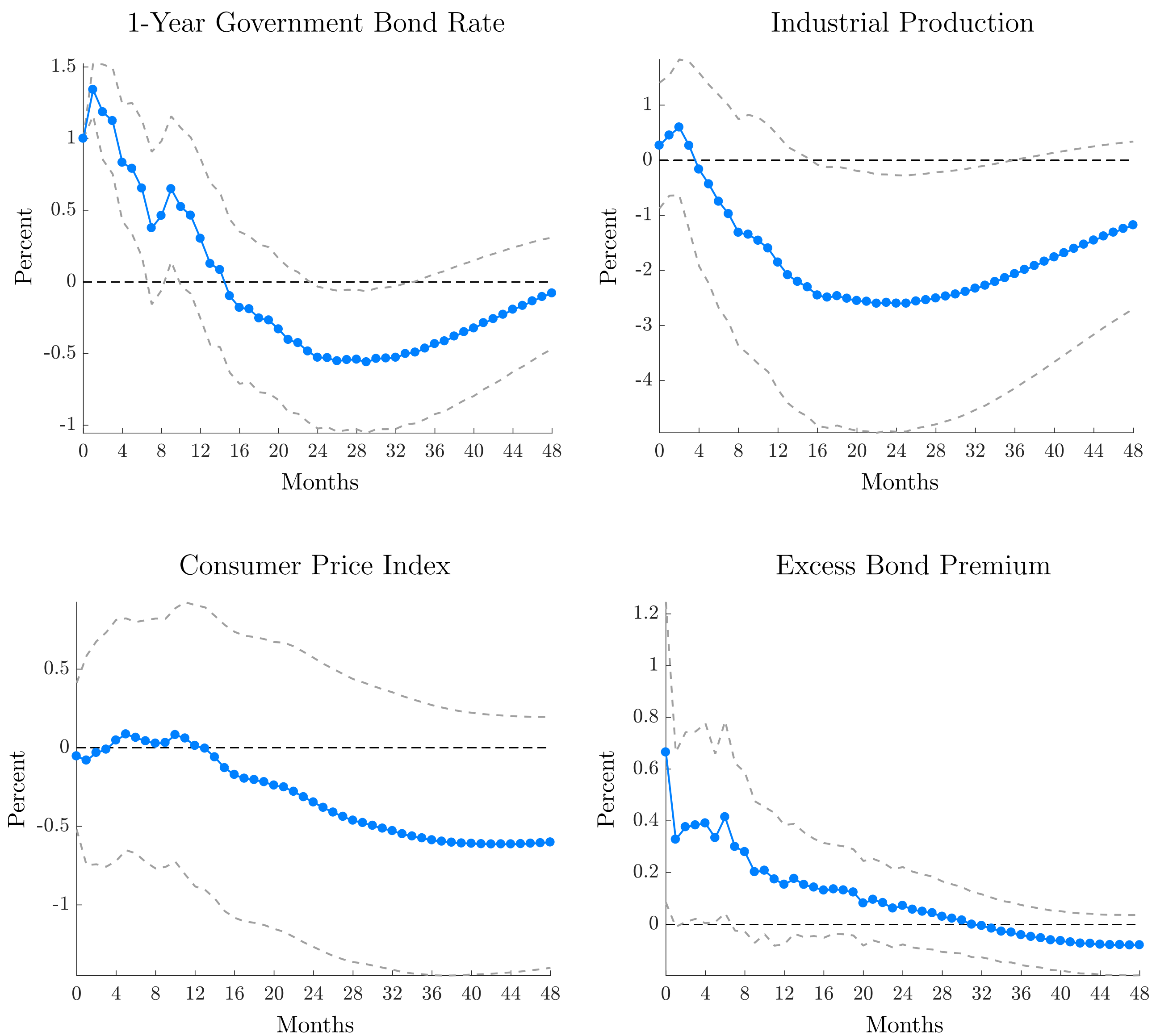

Figure A7. Replication of Gertler and Karadi (2015). Response of the 1-year government bond rate, industrial production, the consumer price index, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using SVAR-IV with unit effect normalization, during the entire period. Sample period: 1979:7-2012:6. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 22.4, and the heteroscedasticity-robust first-stage F-statistic is 21.

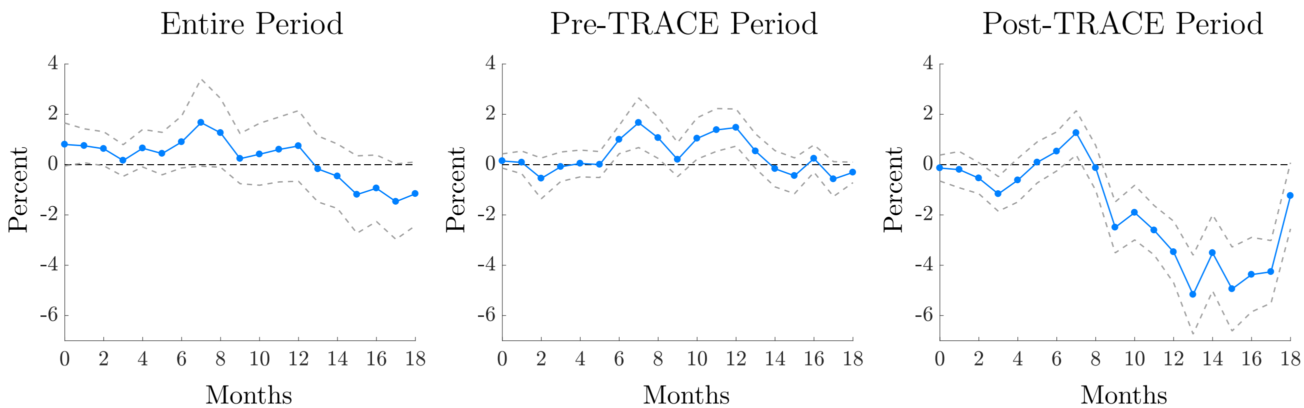

Figure B1. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using Factor-Augmented LP-IV with unit effect normalization. Sample period: 1990:2–2016:12; pre-TRACE period: 1990:2–2003:2; post-TRACE period: 2003:3–2016:12. Dashed lines are the 95% confidence interval. For details, refer to the notes in Figure C4 for the entire period, Figure C5 for the pre-TRACE period, and Figure C6 for the post-TRACE period.

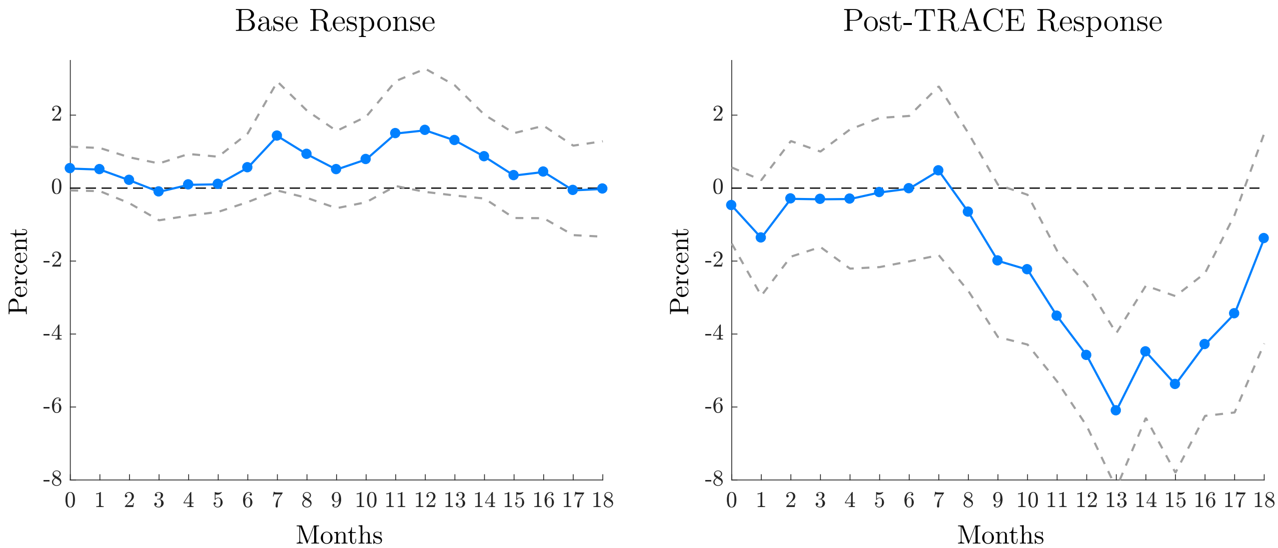

Figure B2. Base and post-TRACE responses of the excess bond premium to a one-percent increase in the nominal policy rate, estimated using LP-IV with unit effect normalization. Sample period: 1990:2–2016:12; post-TRACE period: 2003:3–2016:12. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 15, and the heteroscedasticity-robust first-stage F-statistic is 10.7.

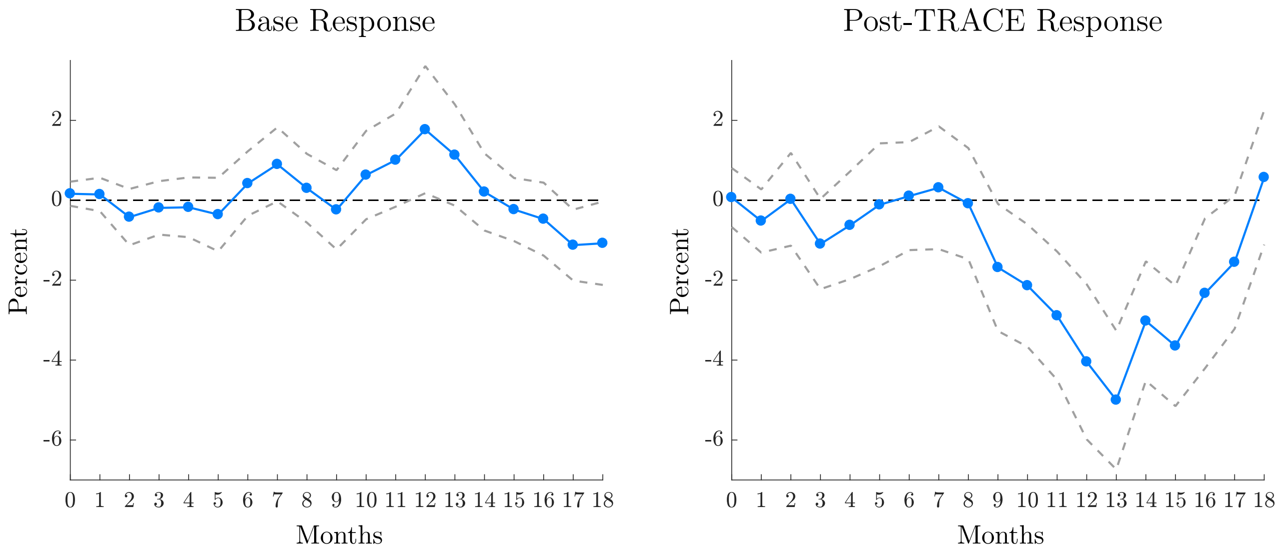

Figure B3. Base and post-TRACE responses of the excess bond premium to a one-percent increase in the nominal policy rate, estimated using Factor-Augmented LP-IV with unit effect normalization. Sample period: 1990:2–2016:12; post-TRACE period: 2003:3–2016:12. 12-month lags of the four main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.7, and the heteroscedasticity-robust first-stage F-statistic is 18.6.

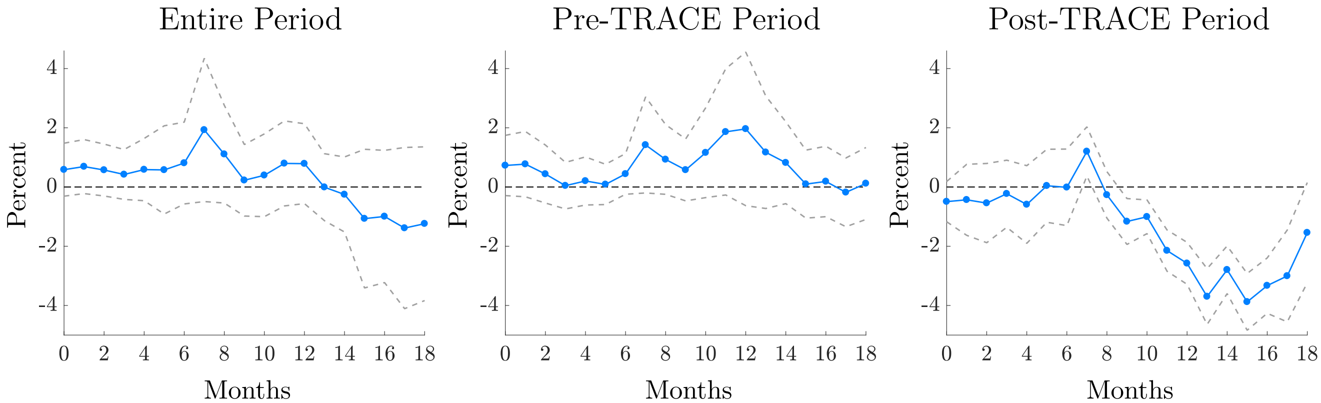

Figure B4. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using LP-IV with unit effect normalization. Sample period: 1990:2–2016:12; pre-TRACE period: 1990:2–2003:2; post-TRACE period: 2003:3–2016:12. 12-month lags of the four main variables (2-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium) and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic and the heteroscedasticity-robust first-stage F-statistic are 14.2 and 8.3 for the entire period, 7.7 and 9 for the pre-TRACE period, and 10.6 and 12.7 for the post-TRACE period.

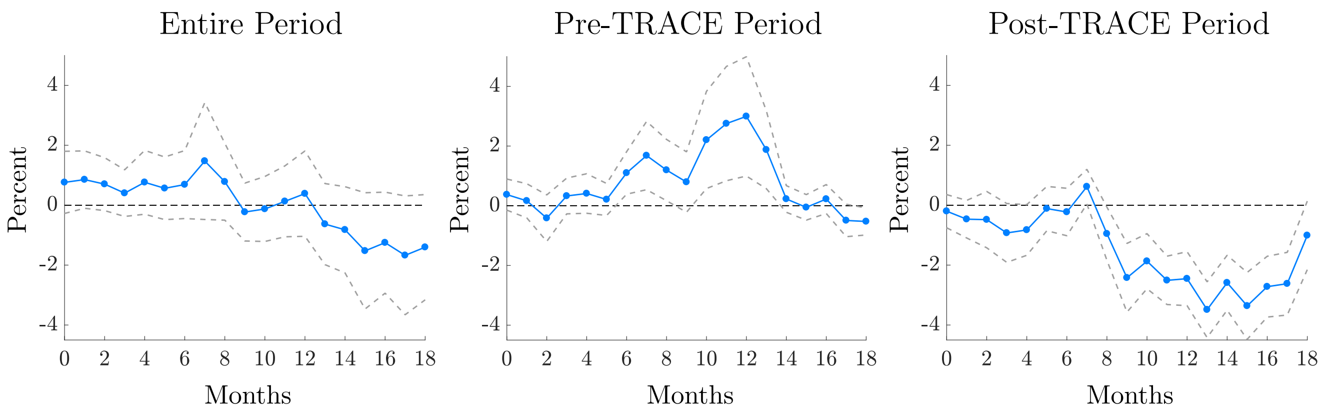

Figure B5. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using Factor-Augmented LP-IV with unit effect normalization. Sample period: 1990:2–2016:12; pre-TRACE period: 1990:2–2003:2; post-TRACE period: 2003:3–2016:12. 12-month lags of the four main variables (2-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium) and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic and the heteroscedasticity-robust first-stage F-statistic are 12.5 and 13 for the entire period, 3.2 and 11 for the pre-TRACE period, and 12.2 and 23 for the post-TRACE period.

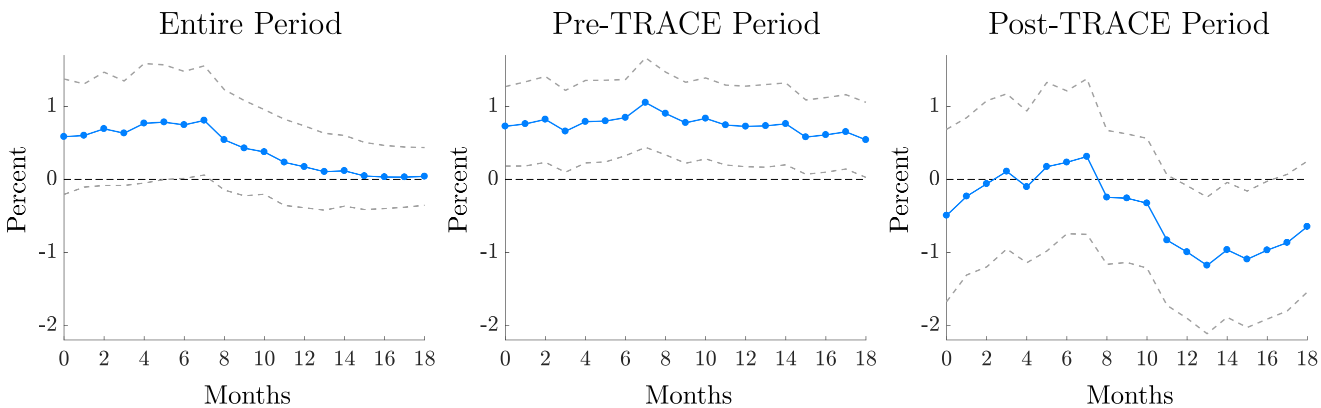

Figure B6. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using SVAR-IV with unit effect normalization. Sample period: 1990:2–2016:12; pre-TRACE period: 1990:2–2003:2; post-TRACE period: 2003:3–2016:12. 12-month lags of the four main variables (2-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium) and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic and the heteroscedasticity-robust first-stage F-statistic are 14.2 and 8.3 for the entire period, 7.7 and 9 for the pre-TRACE period, and 10.6 and 12.7 for the post-TRACE period.

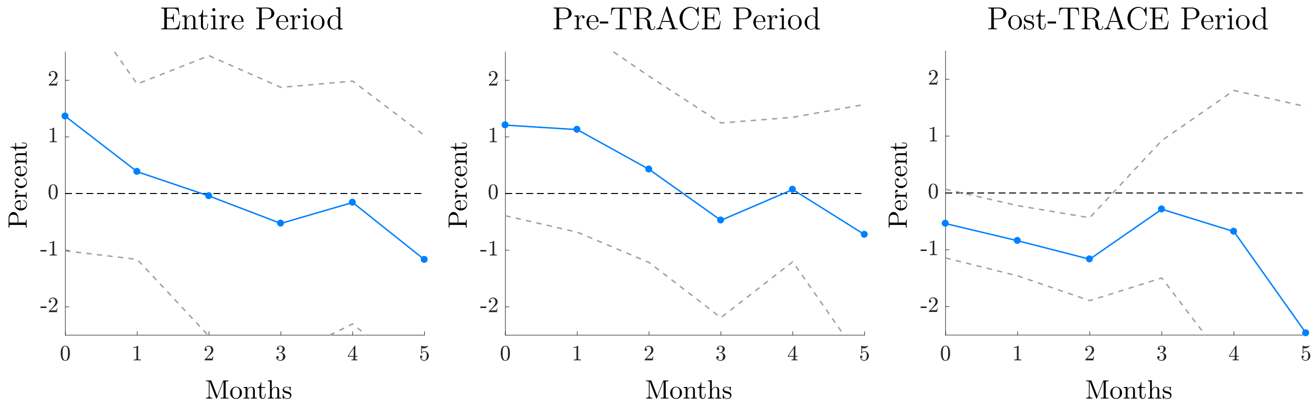

Figure B7. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using LP-IV with unit effect normalization, during the short period around the introduction of the TRACE. Sample period: 1997:11–2008:6; pre-TRACE period: 1997:11–2003:2; post-TRACE period: 2003:3–2008:6. 4-month lags of the four main variables and 2-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic and the heteroscedasticity-robust first-stage F-statistic are 2.5 and 1.7 for the entire period, 2.9 and 2.7 for the pre-TRACE period, and 4.2 and 5.6 for the post-TRACE period.

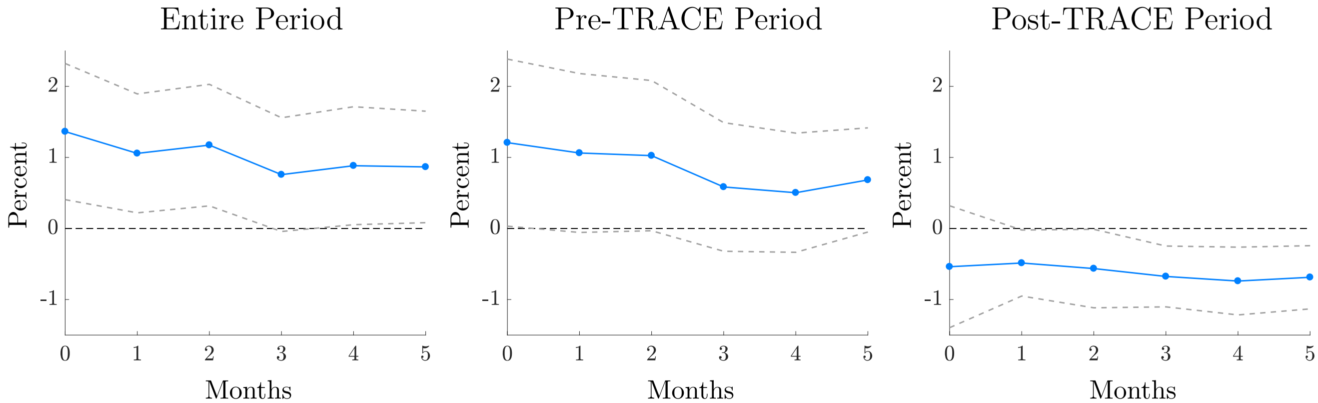

Figure B8. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using SVAR-IV with unit effect normalization, during the short period around the introduction of the TRACE. Sample period: 1997:11–2008:6; pre-TRACE period: 1997:11–2003:2; post-TRACE period: 2003:3–2008:6. 4-month lags of the four main variables and 2-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic and the heteroscedasticity-robust first-stage F-statistic are 2.5 and 1.7 for the entire period, 2.9 and 2.7 for the pre-TRACE period, and 4.2 and 5.6 for the post-TRACE period.

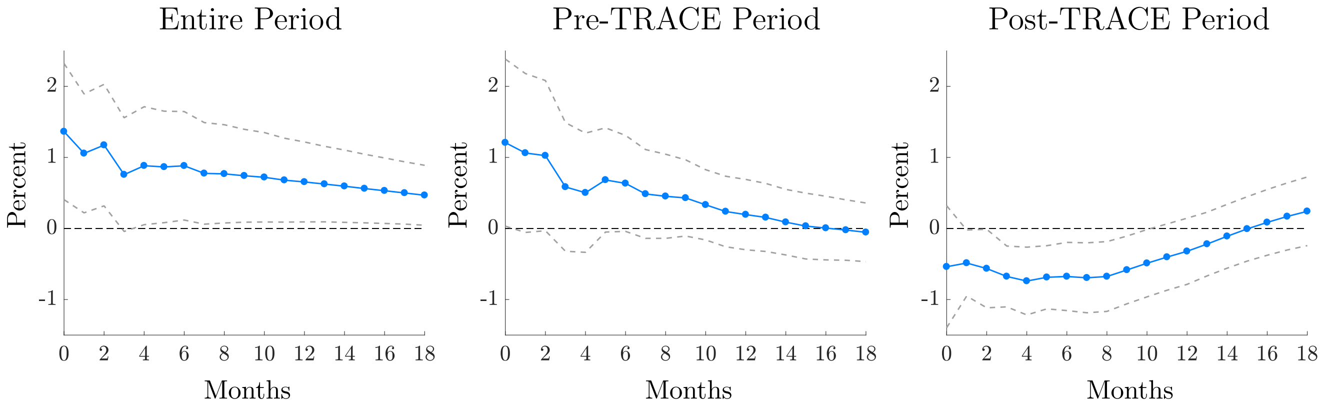

Figure B9. Response of the excess bond premium to a one-percent increase in the nominal policy rate for different sample periods, estimated using SVAR-IV with unit effect normalization, during the short period around the introduction of the TRACE. Sample period: 1997:11–2008:6; pre-TRACE period: 1997:11–2003:2; post-TRACE period: 2003:3–2008:6. 4-month lags of the four main variables and 2-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic and the heteroscedasticity-robust first-stage F-statistic are 2.5 and 1.7 for the entire period, 2.9 and 2.7 for the pre-TRACE period, and 4.2 and 5.6 for the post-TRACE period.

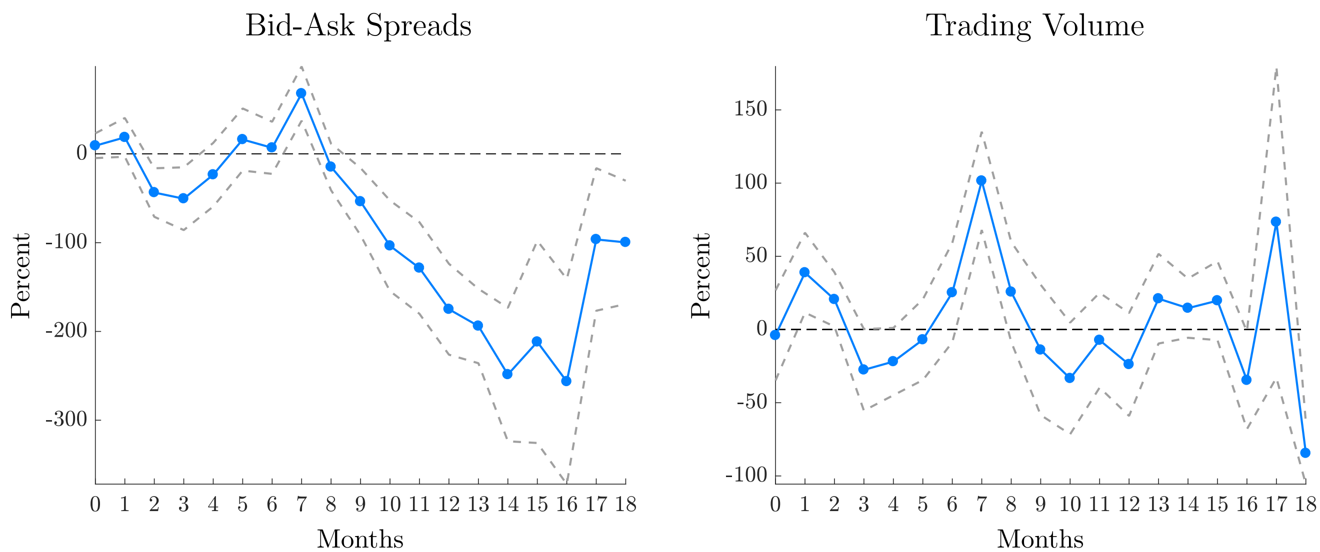

Figure B10. Response of the bid-ask spreads and the trading volume of corporate bonds to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using Factor-Augmented LP-IV with unit effect normalization. Sample period: 2003:3–2016:12. Dashed lines are the 95% confidence interval. For details, refer to the notes in Figure C11 for the bid-ask spreads and Figure C14 for the trading volume.

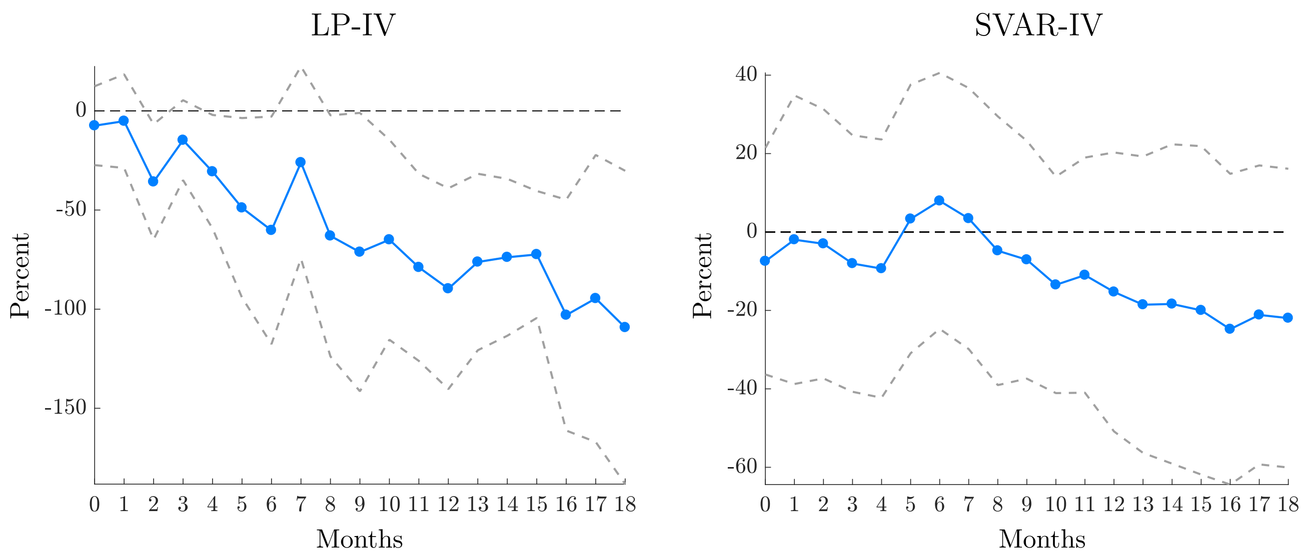

Figure B11. Response of the bid-ask spreads of corporate bonds to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using LP-IV (left) and SVAR-IV (right) with unit effect normalization. Sample period: 2003:3–2016:12. 12-month lags of the six main variables (2-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the bid-ask spreads, and inflation expectation) and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors for LP-IV and the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap for SVAR-IV. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 9, and the heteroscedasticity-robust first-stage F-statistic is 15.6.

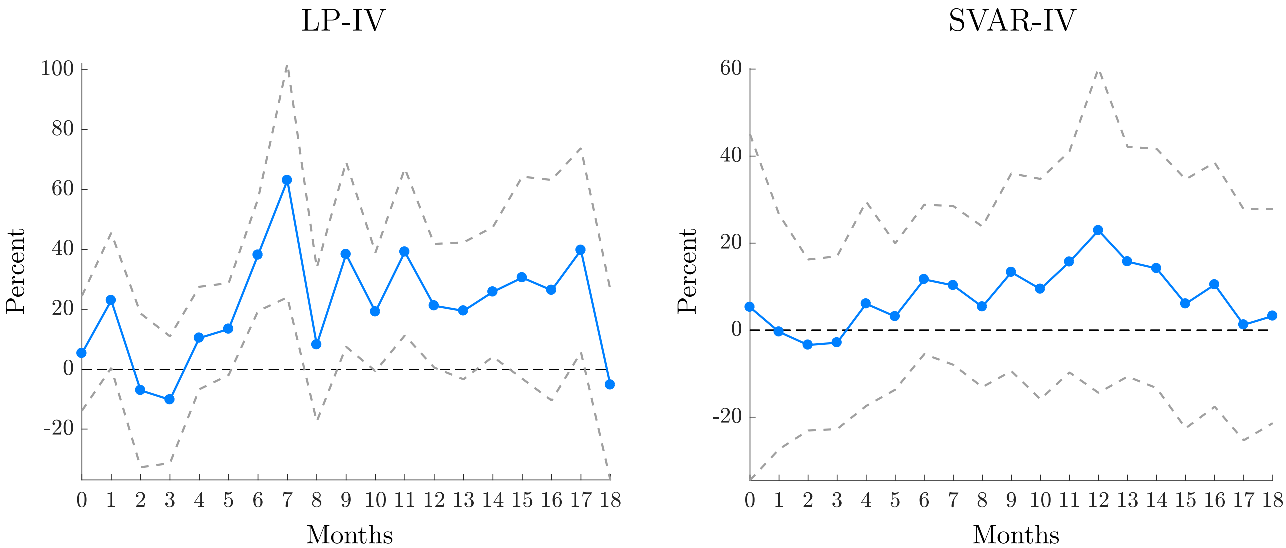

Figure B12. Response of the trading volume of corporate bonds to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using LP-IV (left) and SVAR-IV (right) with unit effect normalization. Sample period: 2003:3–2016:12. 12-month lags of the six main variables (2-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the trading volume, and inflation expectation) and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors for LP-IV and the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap for SVAR-IV. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 11.5, and the heteroscedasticity-robust first-stage F-statistic is 21.

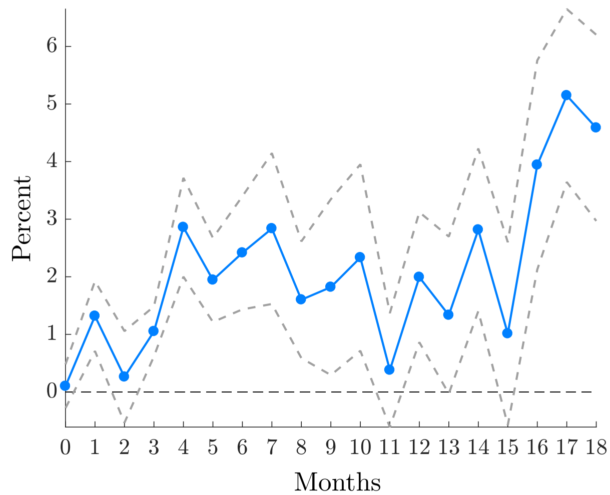

Figure B13. Response of the real loan rate to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using Factor-Augmented LP-IV with unit effect normalization. Sample period: 2003:3–2016:12. Dashed lines are the 95% confidence interval. For details, refer to the notes in Figure C17.

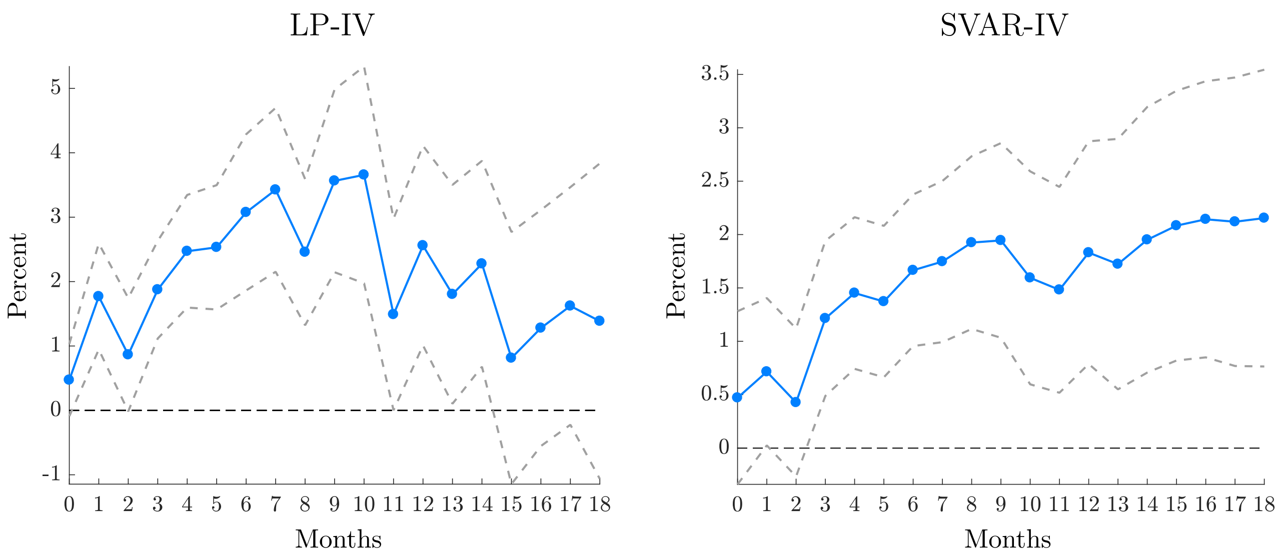

Figure B14. Response of the real loan rate to a one-percent increase in the nominal policy rate during the post-TRACE period, estimated using LP-IV (left) and SVAR-IV (right) with unit effect normalization. Sample period: 2003:3–2016:12. 12-month lags of the five main variables (2-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, and the real loan rate) and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors for LP-IV and the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap for SVAR-IV. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 8.6, and the heteroscedasticity-robust first-stage F-statistic is 11.7.

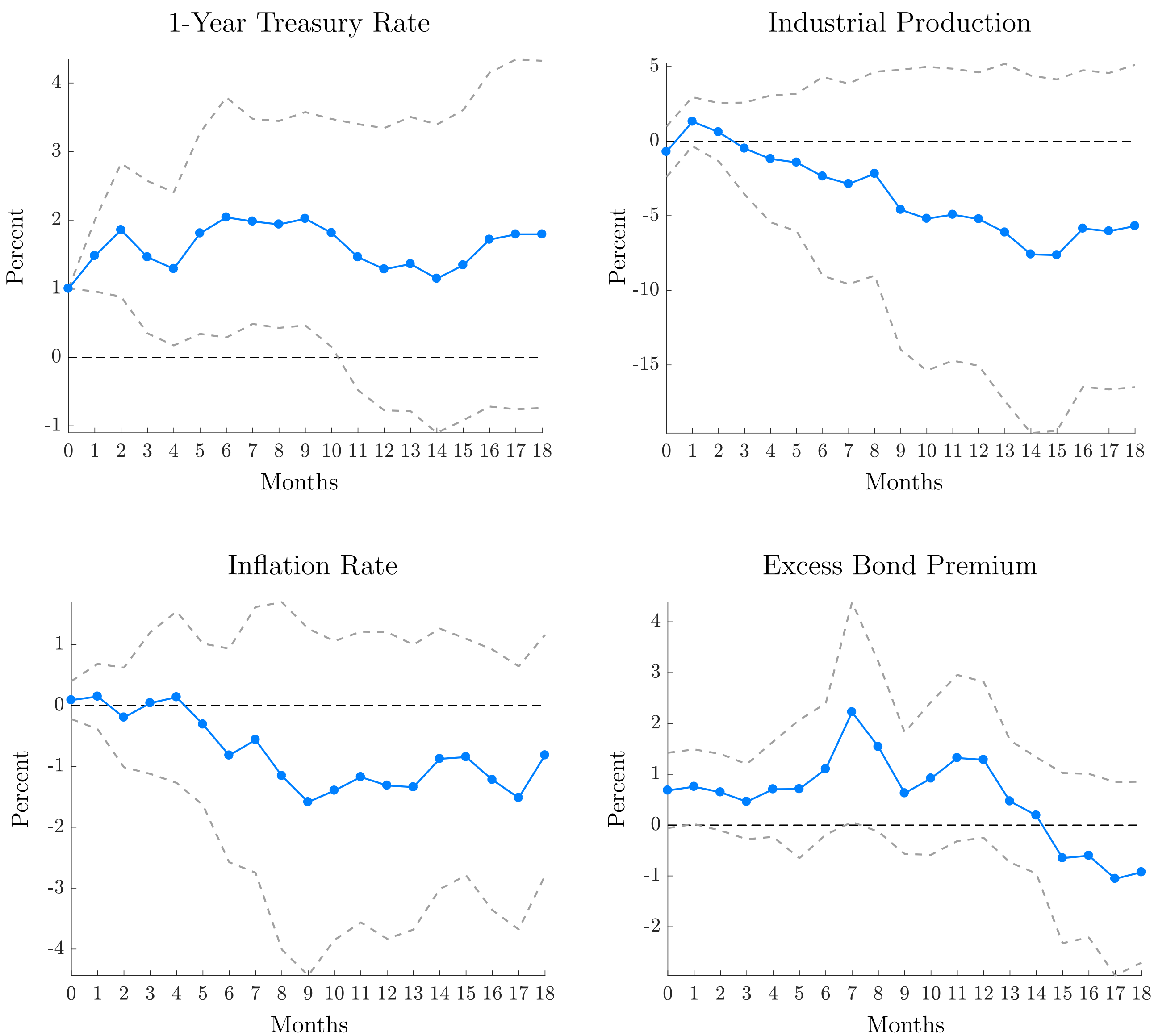

Figure C1. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using LP-IV with unit effect normalization, during the entire period. Sample period: 1990:2–2016:12. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 22, and the heteroscedasticity-robust first-stage F-statistic is 14.5.

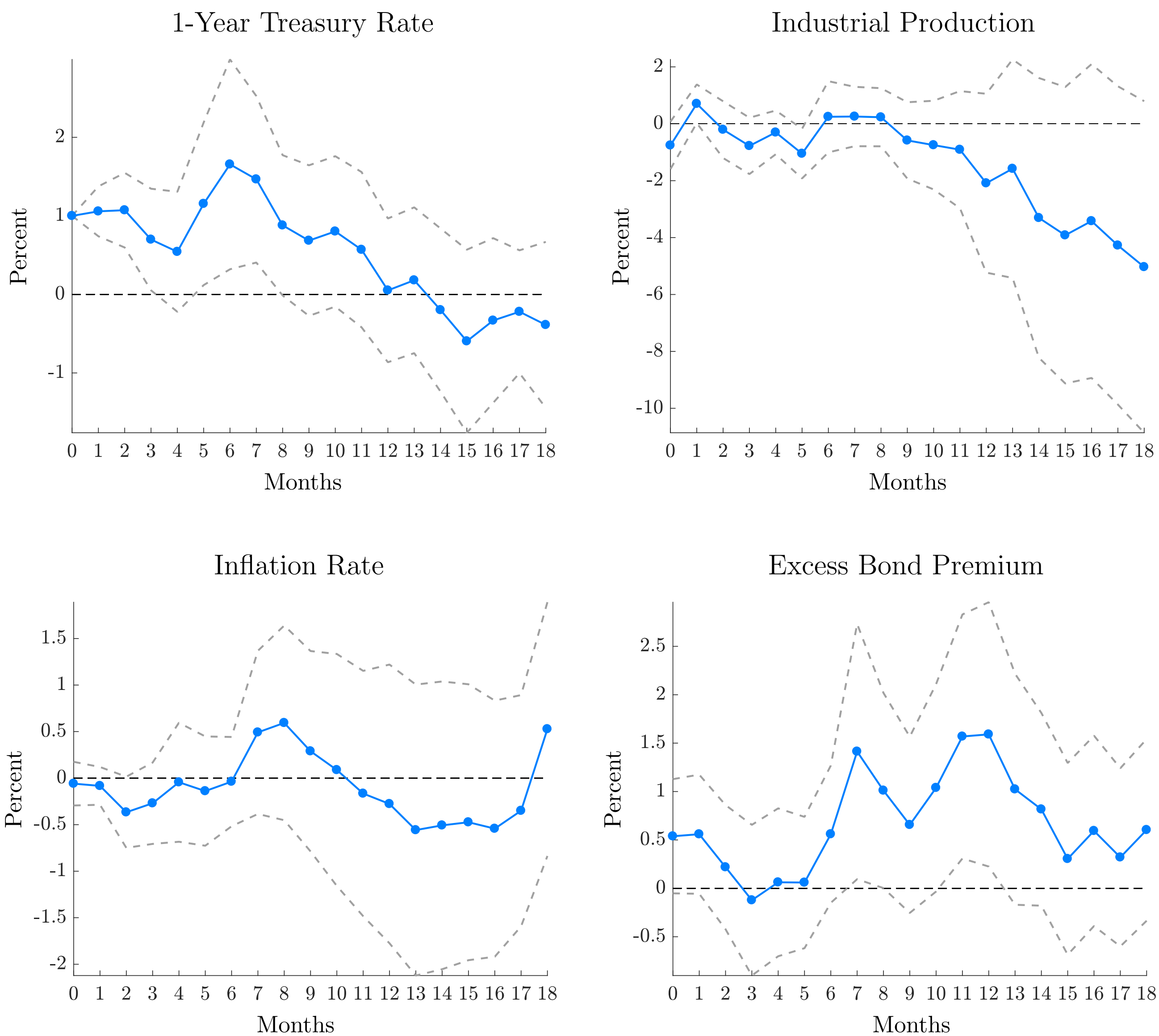

Figure C2. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using LP-IV with unit effect normalization, during the pre-TRACE period. Sample period: 1990:2–2003:2. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 15.6, and the heteroscedasticity-robust first-stage F-statistic is 19.4.

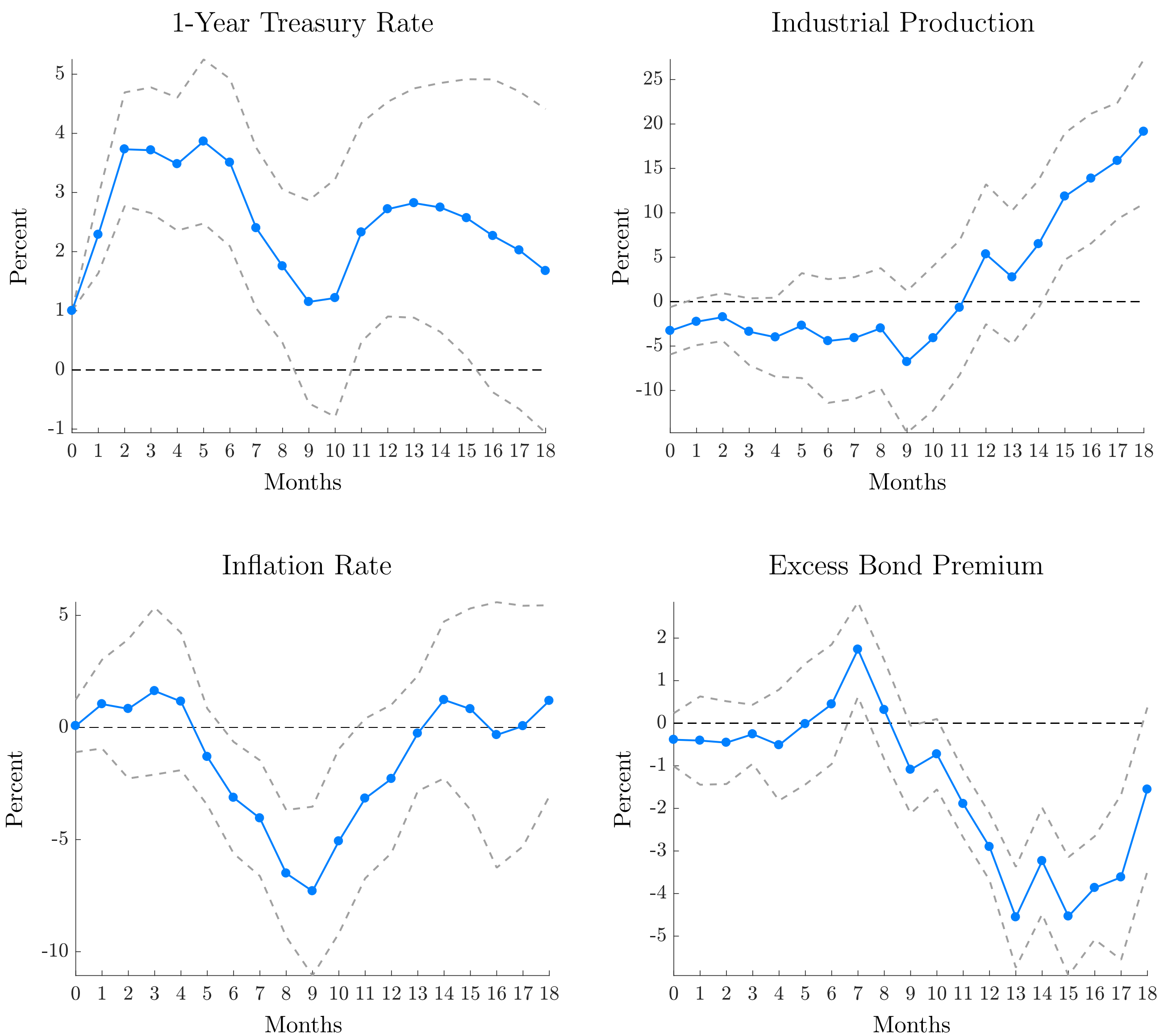

Figure C3. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.1, and the heteroscedasticity-robust first-stage F-statistic is 14.7.

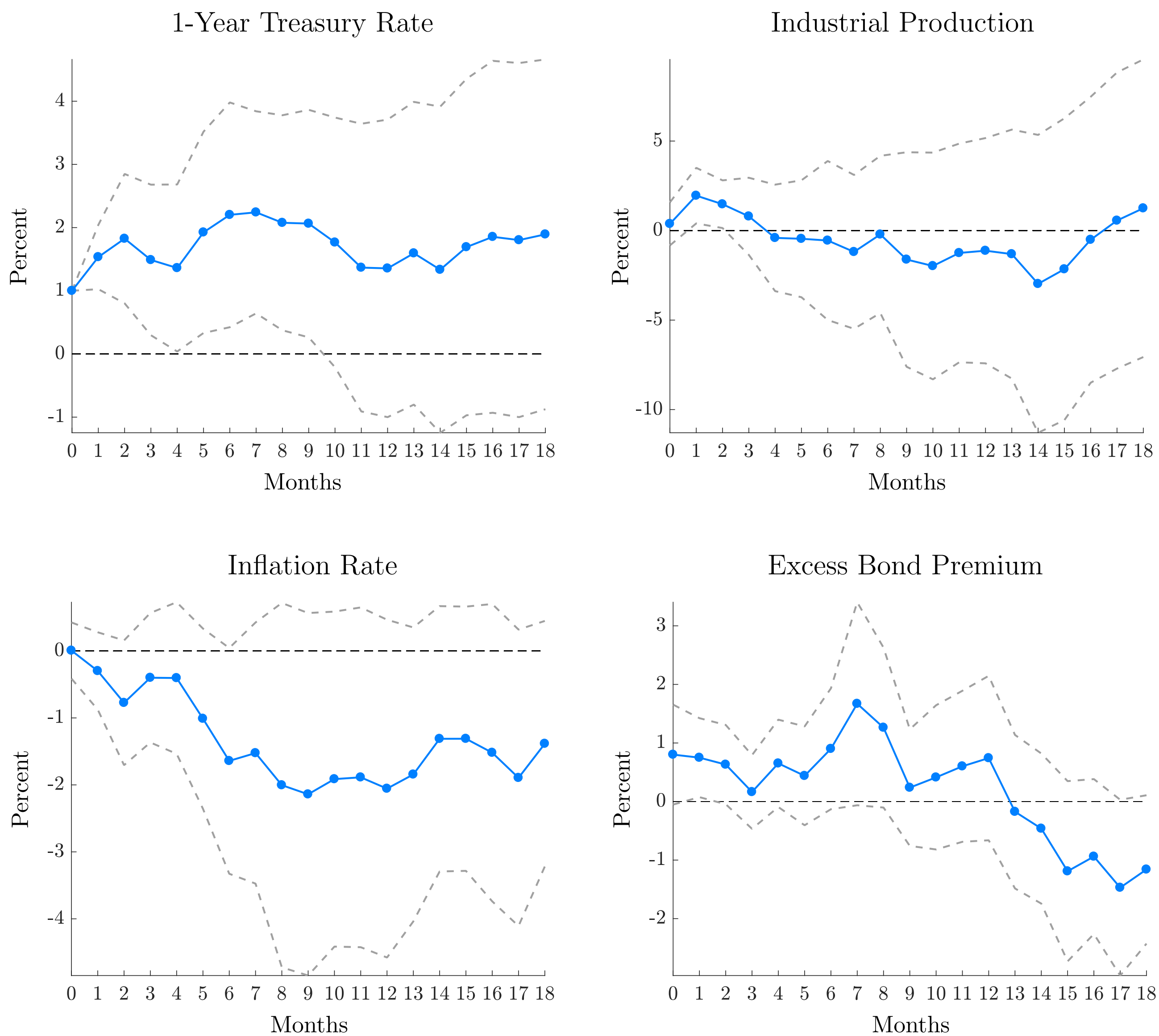

Figure C4. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using Factor-Augmented LP-IV with unit effect normalization, during the entire period. Sample period: 1990:2–2016:12. 12-month lags of the four main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 19.1, and the heteroscedasticity-robust first-stage F-statistic is 22.3.

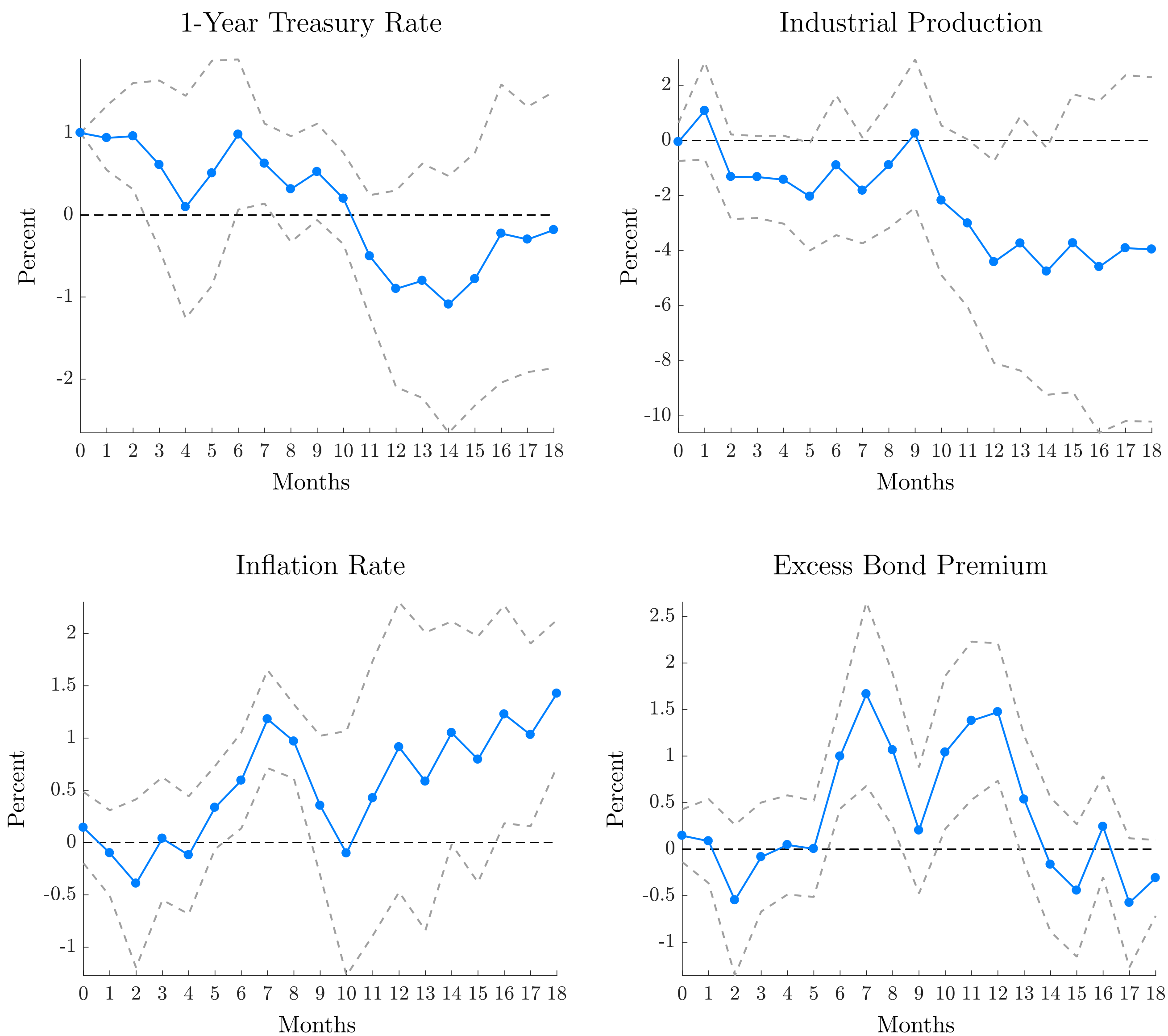

Figure C5. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using Factor-Augmented LP-IV with unit effect normalization, during the pre-TRACE period. Sample period: 1990:2–2003:2. 12-month lags of the four main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 6, and the heteroscedasticity-robust first-stage F-statistic is 21.4.

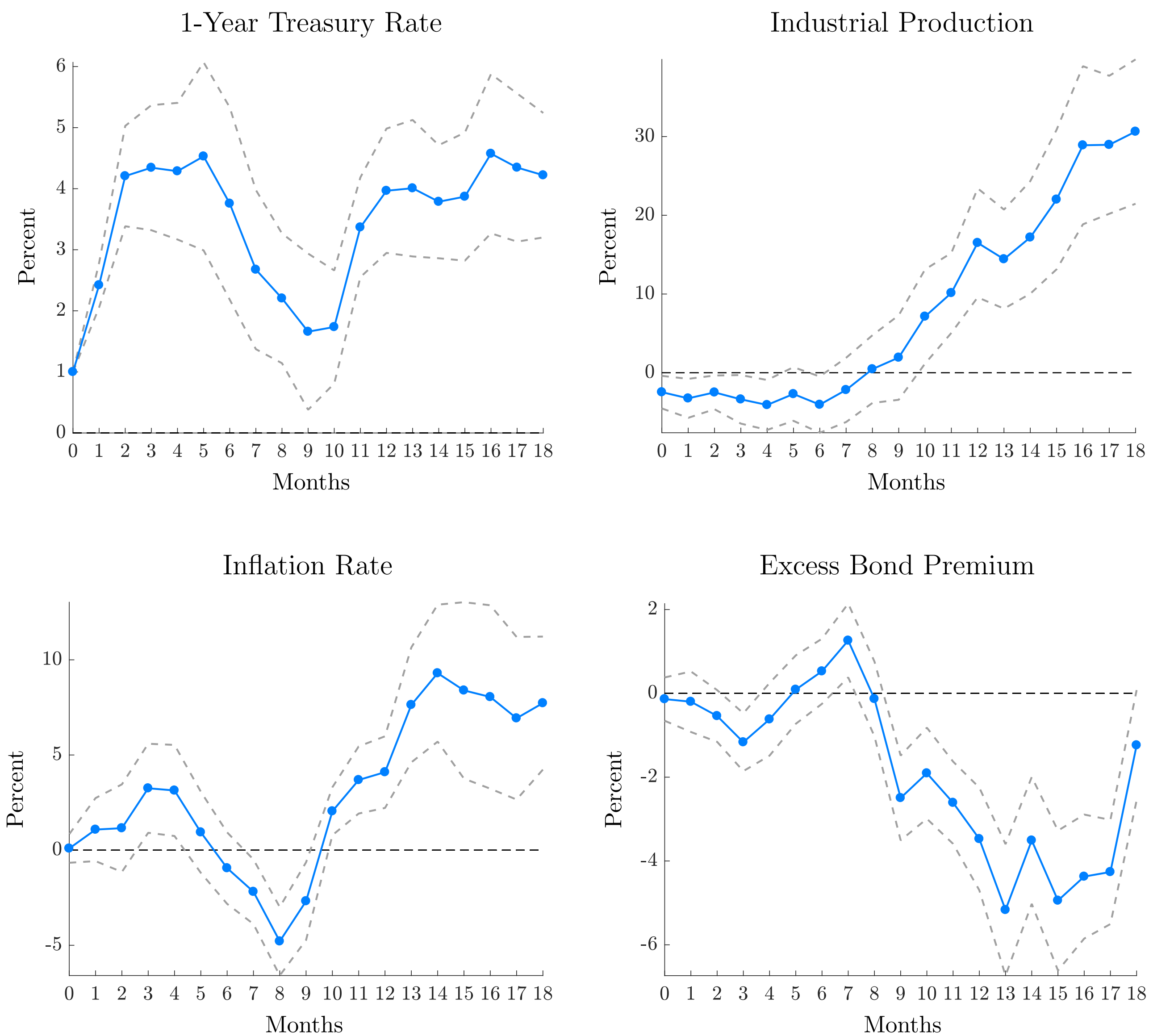

Figure C6. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using Factor-Augmented LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the four main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 10.7, and the heteroscedasticity-robust first-stage F-statistic is 20.4.

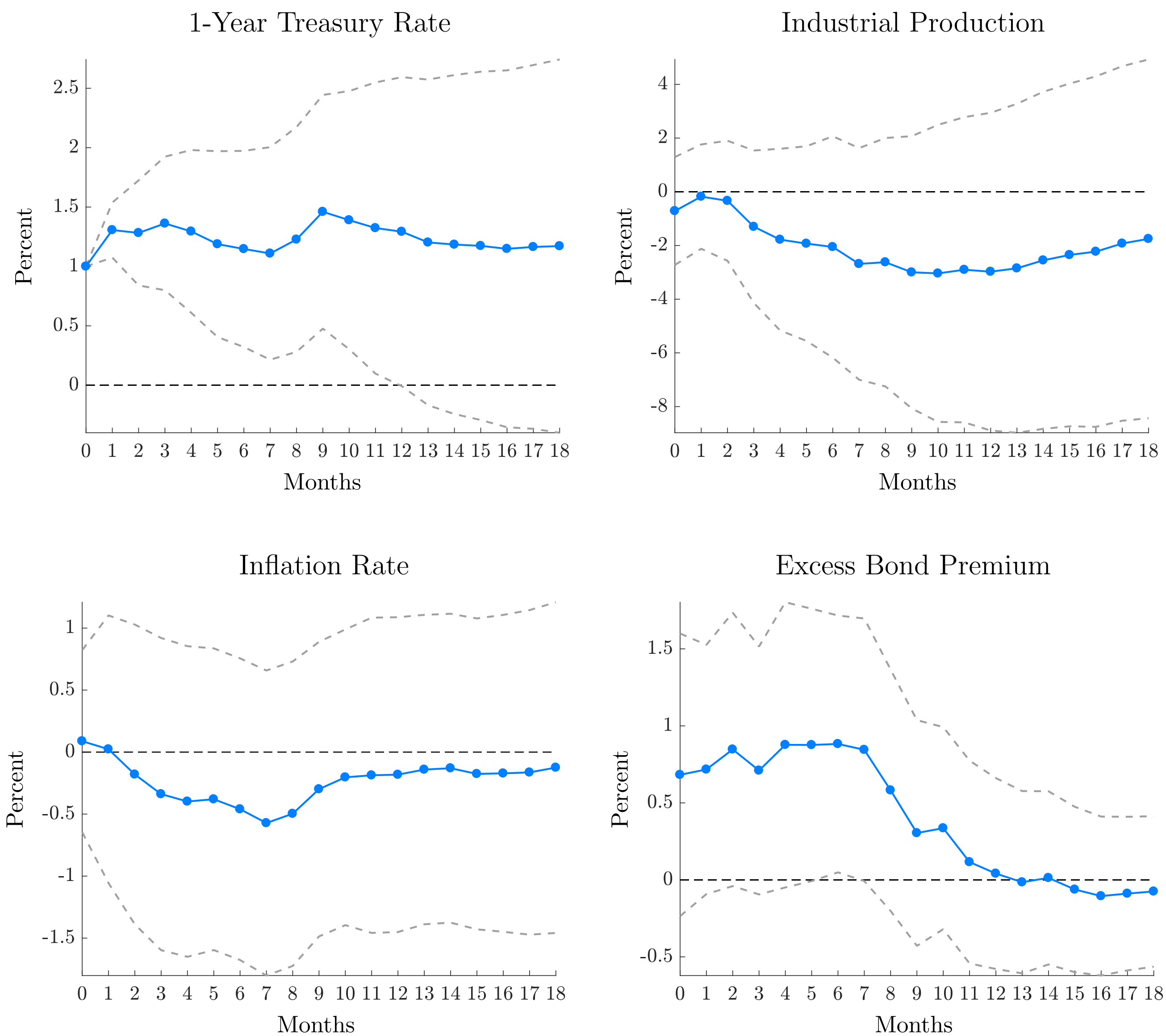

Figure C7. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using SVAR-IV with unit effect normalization, during the entire period. Sample period: 1990:2–2016:12. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 22, and the heteroscedasticity-robust first-stage F-statistic is 14.5.

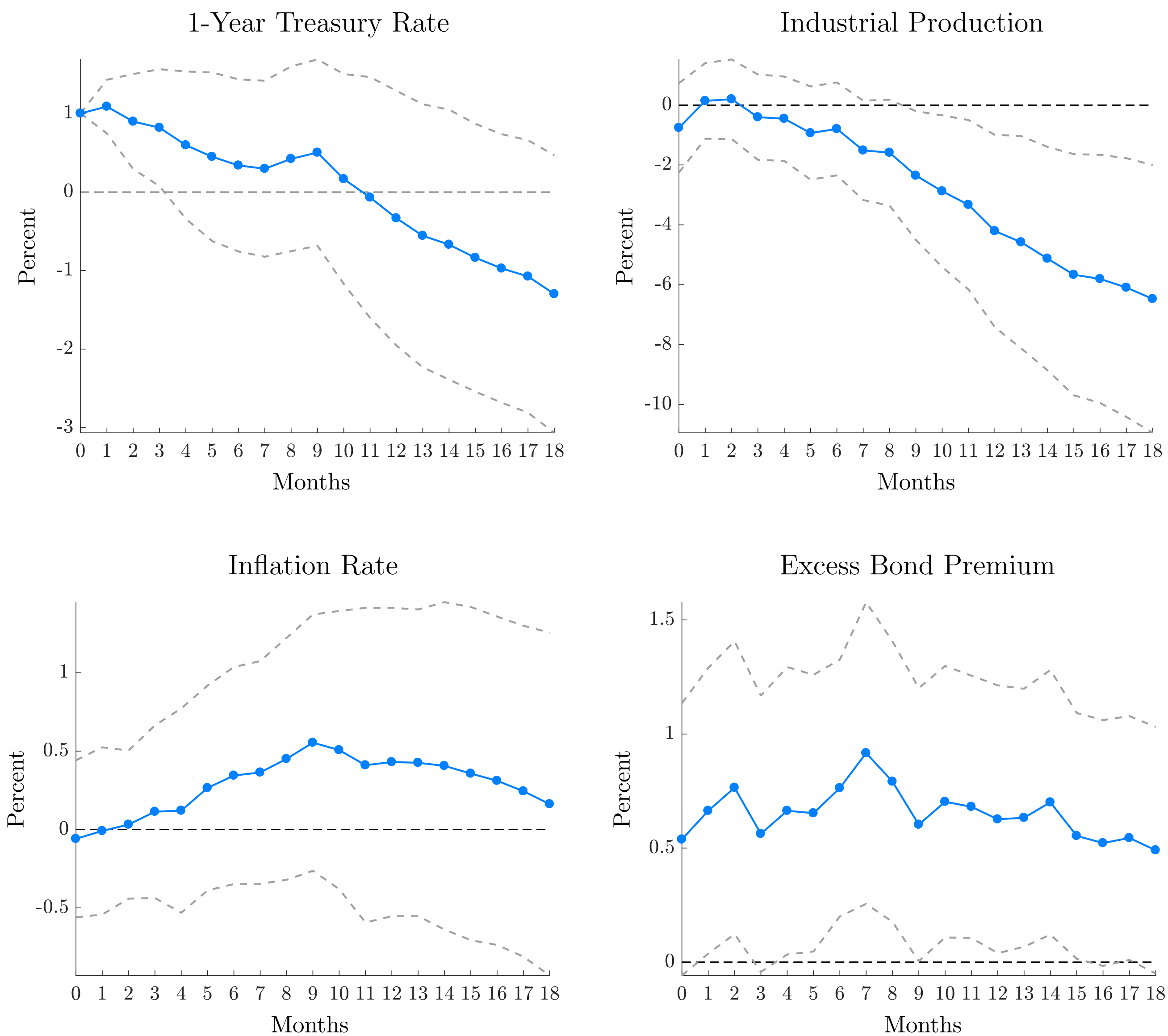

Figure C8. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using SVAR-IV with unit effect normalization, during the pre-TRACE period. Sample period: 1990:2–2003:2. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 15.6, and the heteroscedasticity-robust first-stage F-statistic is 19.4.

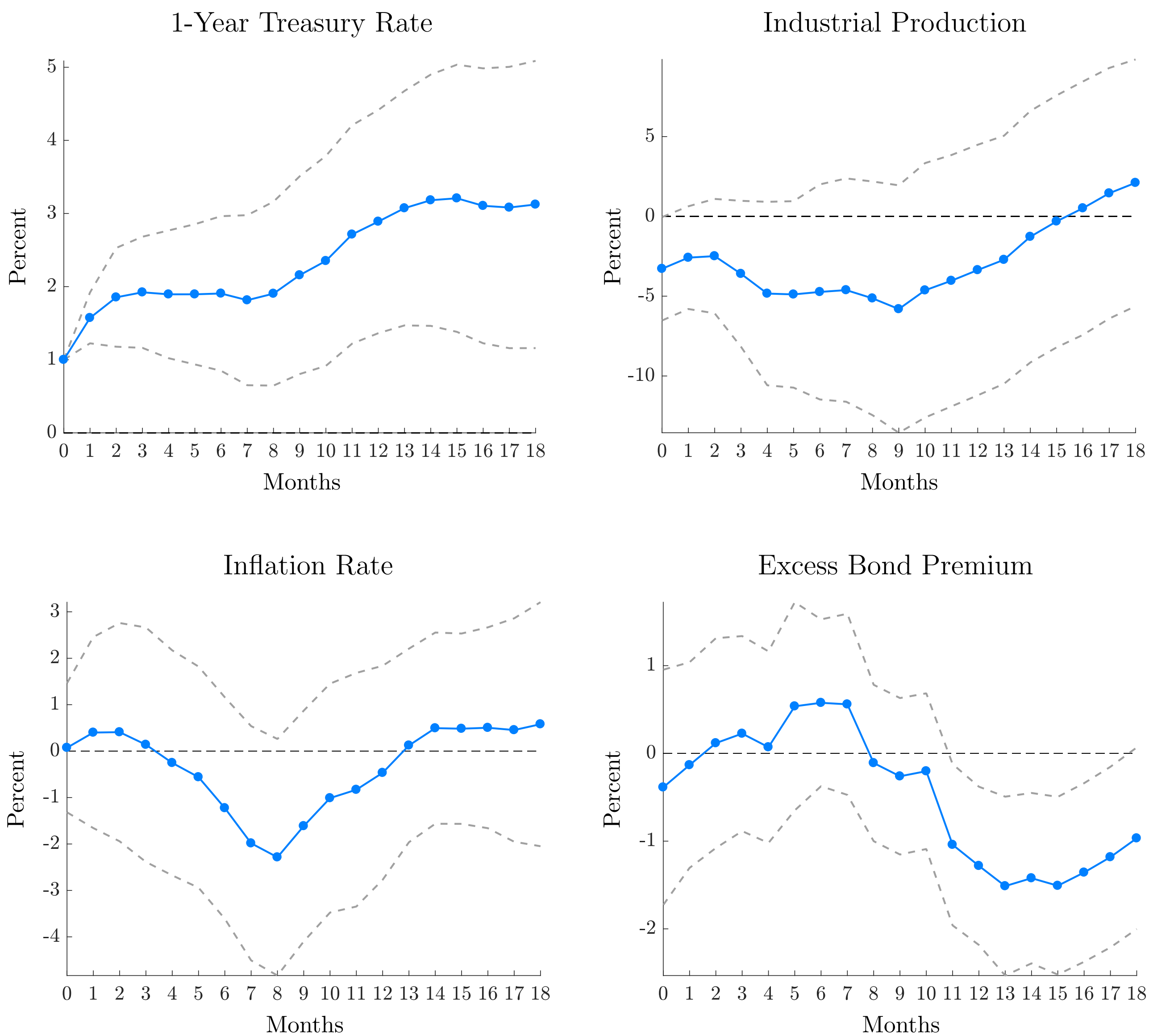

Figure C9. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, and the excess bond premium to a one-percent increase in the nominal policy rate, estimated using SVAR-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the four main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.1, and the heteroscedasticity-robust first-stage F-statistic is 14.7.

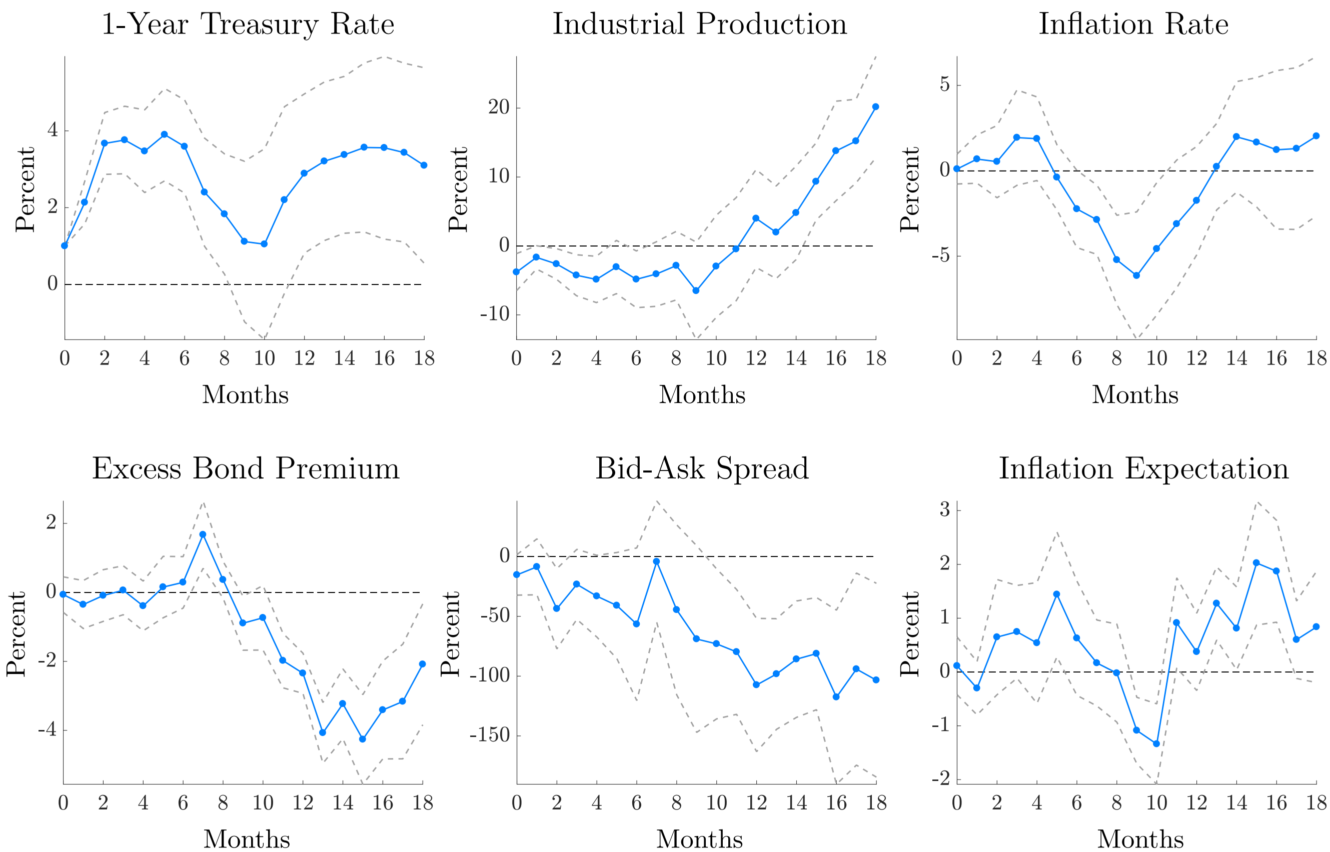

Figure C10. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the bid-ask spreads, and the inflation expectation, estimated using LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the six main variables and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 11.4, and the heteroscedasticity-robust first-stage F-statistic is 17.5.

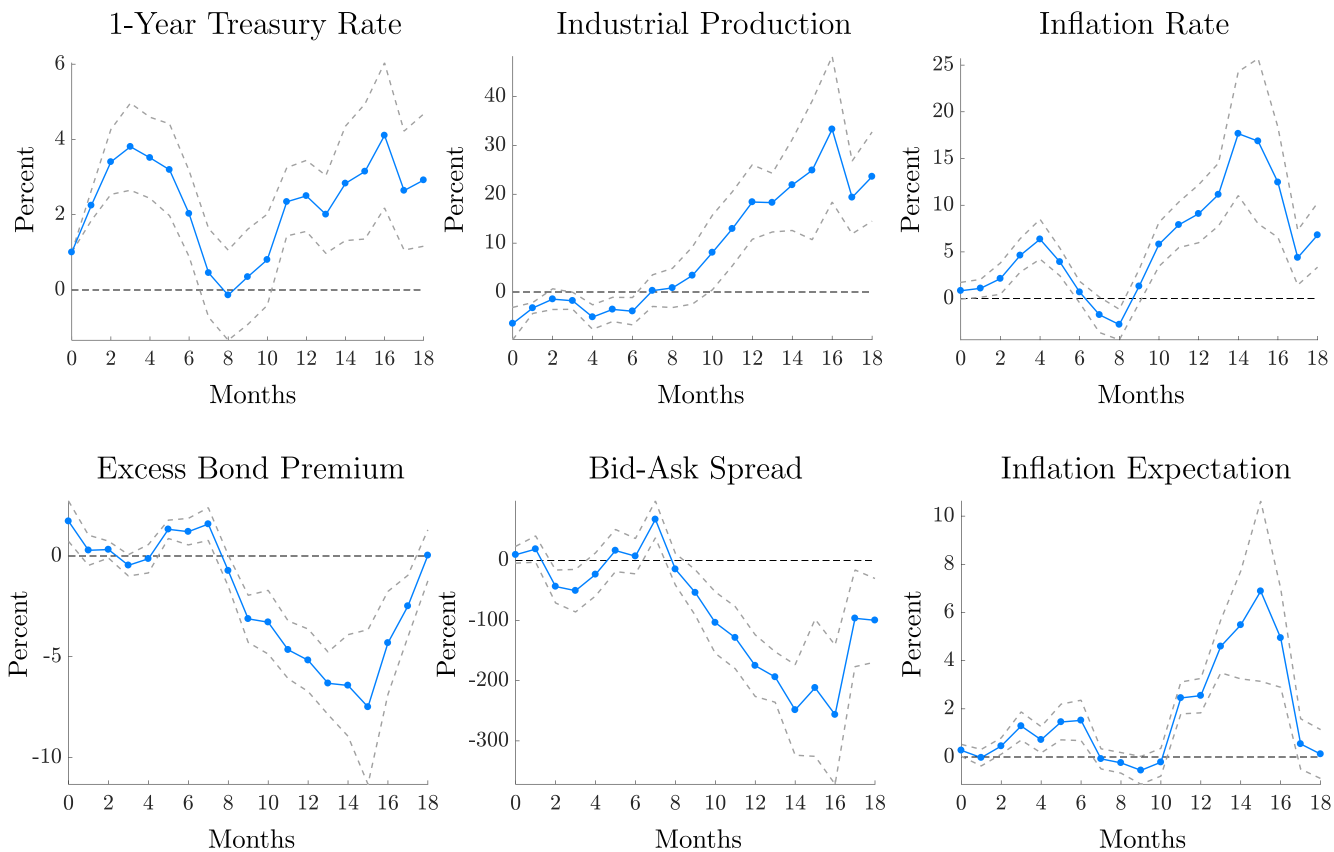

Figure C11. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the bid-ask spreads, and the inflation expectation, estimated using Factor-Augmented LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the six main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 5.6, and the heteroscedasticity-robust first-stage F-statistic is 25.9.

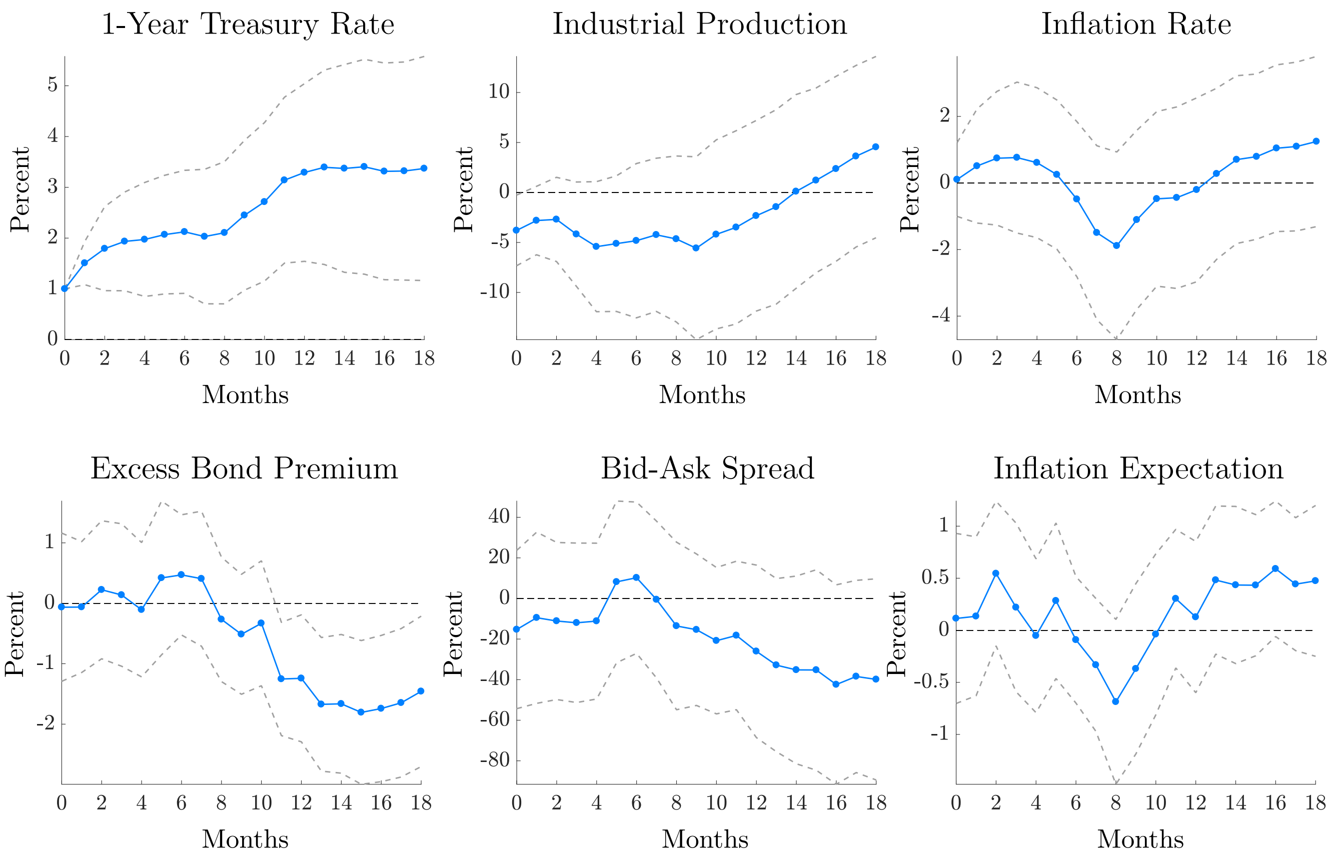

Figure C12. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the bid-ask spreads, and the inflation expectation, estimated using SVAR-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the six main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 11.4, and the heteroscedasticity-robust first-stage F-statistic is 17.5.

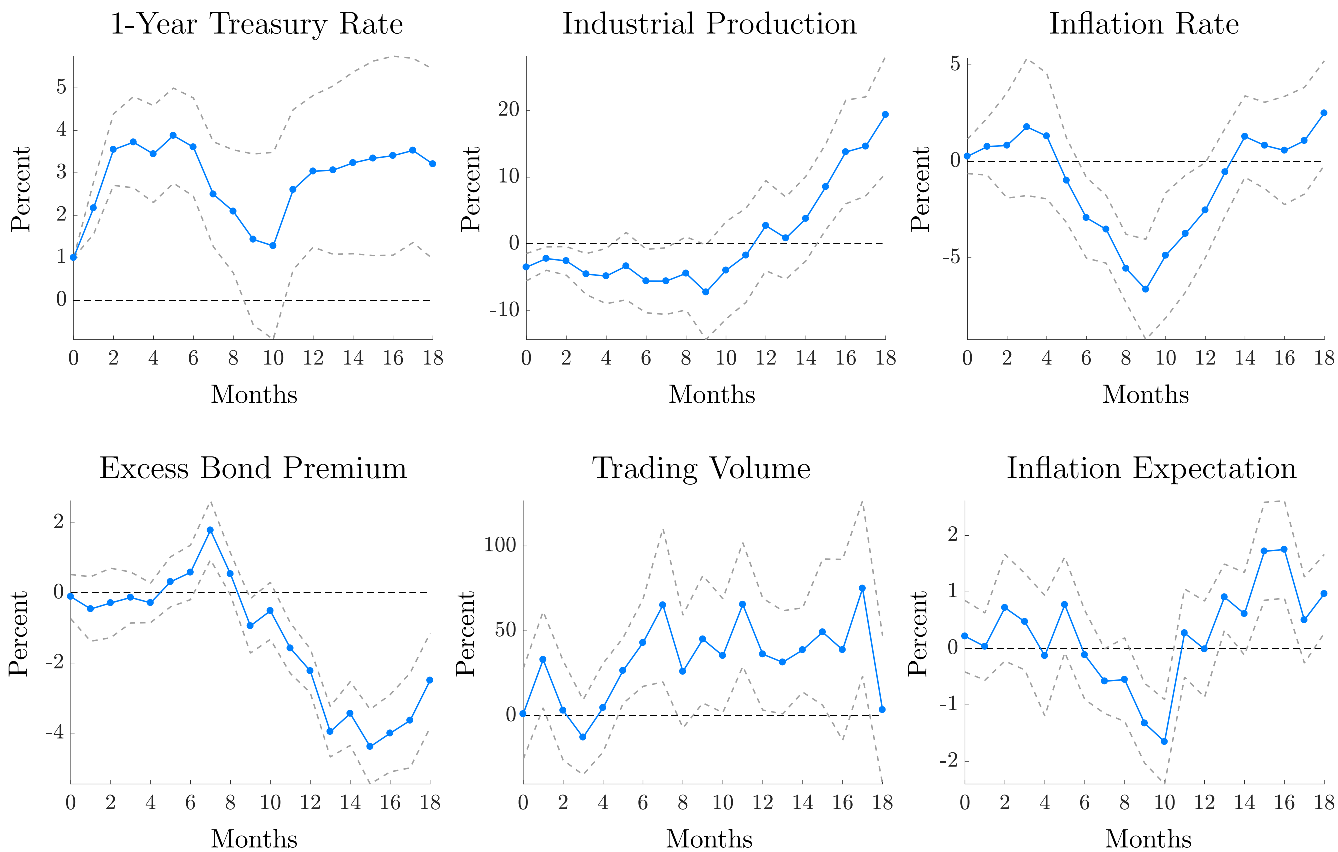

Figure C13. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the trading volume, and the inflation expectation, estimated using LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the six main variables and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.8, and the heteroscedasticity-robust first-stage F-statistic is 25.9.

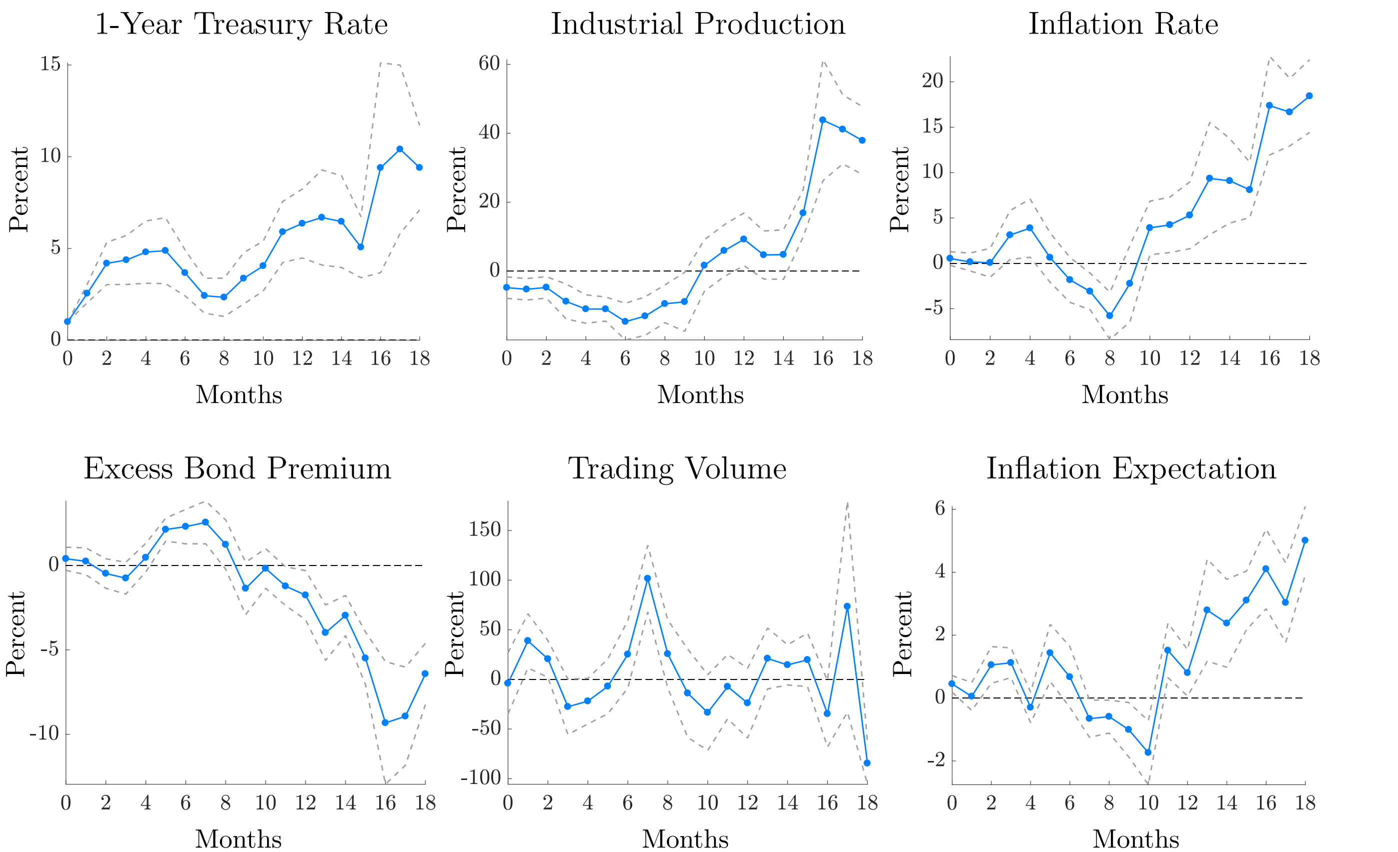

Figure C14. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the trading volume, and the inflation expectation, estimated using Factor-Augmented LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the six main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 5.5, and the heteroscedasticity-robust first-stage F-statistic is 27.5.

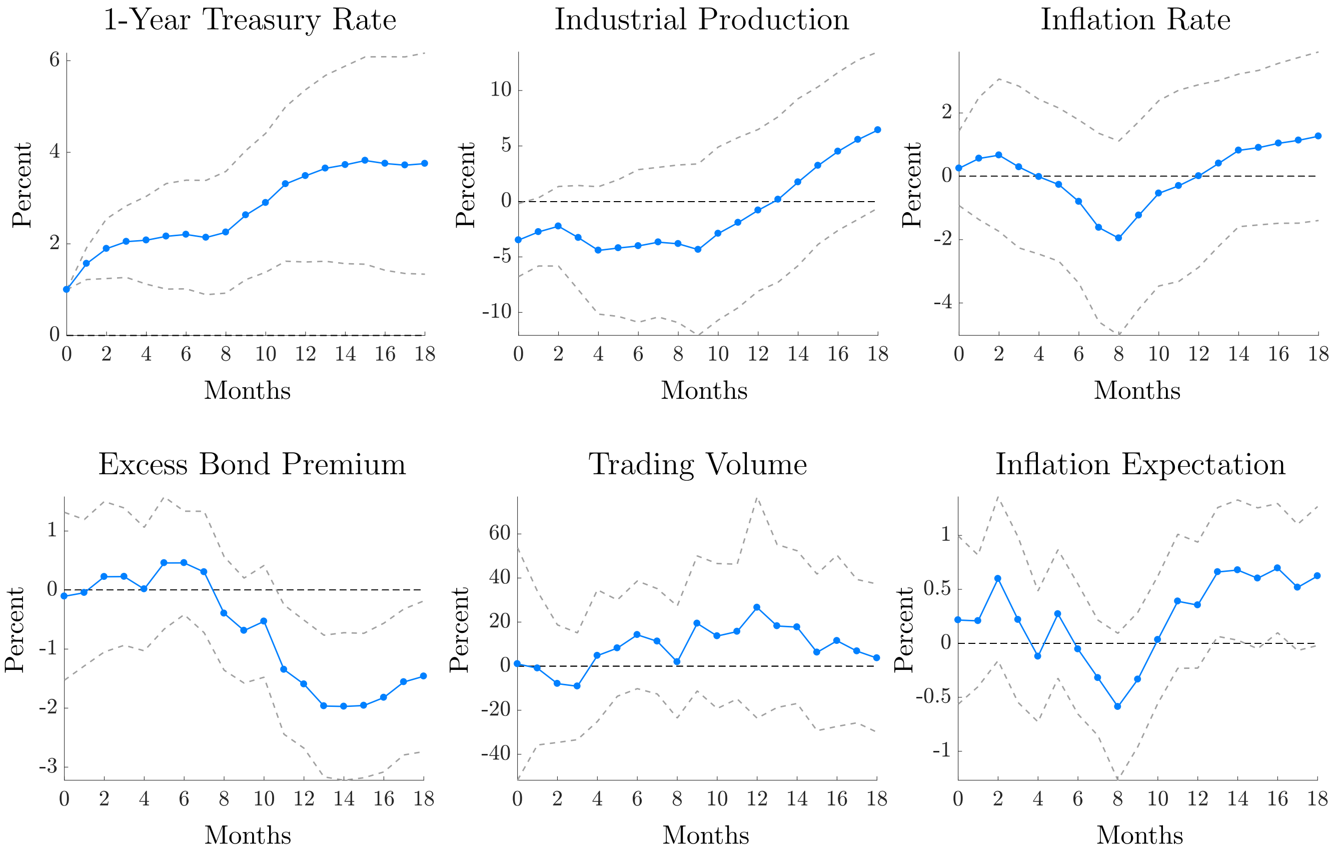

Figure C15. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the trading volume, and the inflation expectation, estimated using SVAR-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the six main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.8, and the heteroscedasticity-robust first-stage F-statistic is 25.9.

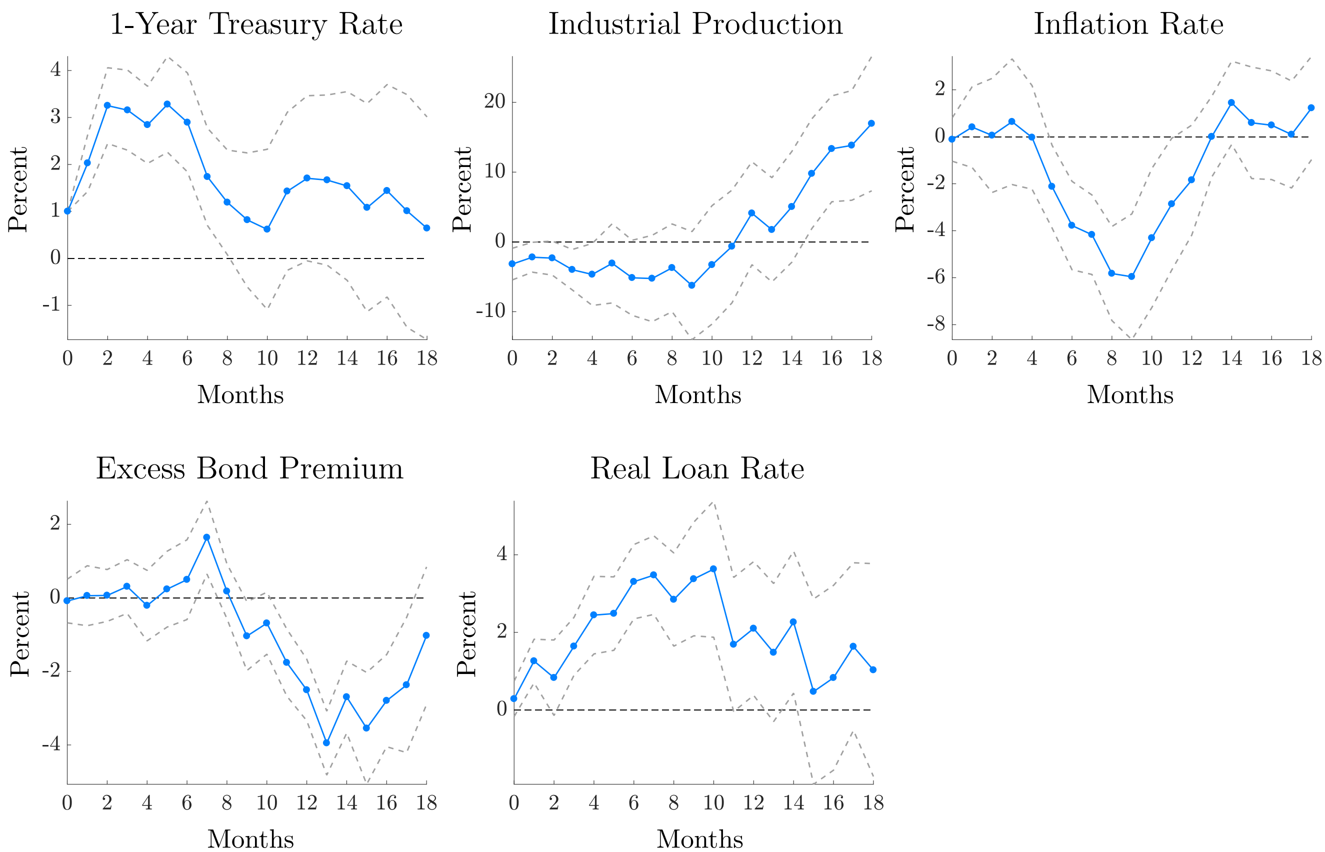

Figure C16. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the real loan rate, and the inflation expectation, estimated using LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the five main variables and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.4, and the heteroscedasticity-robust first-stage F-statistic is 19.4.

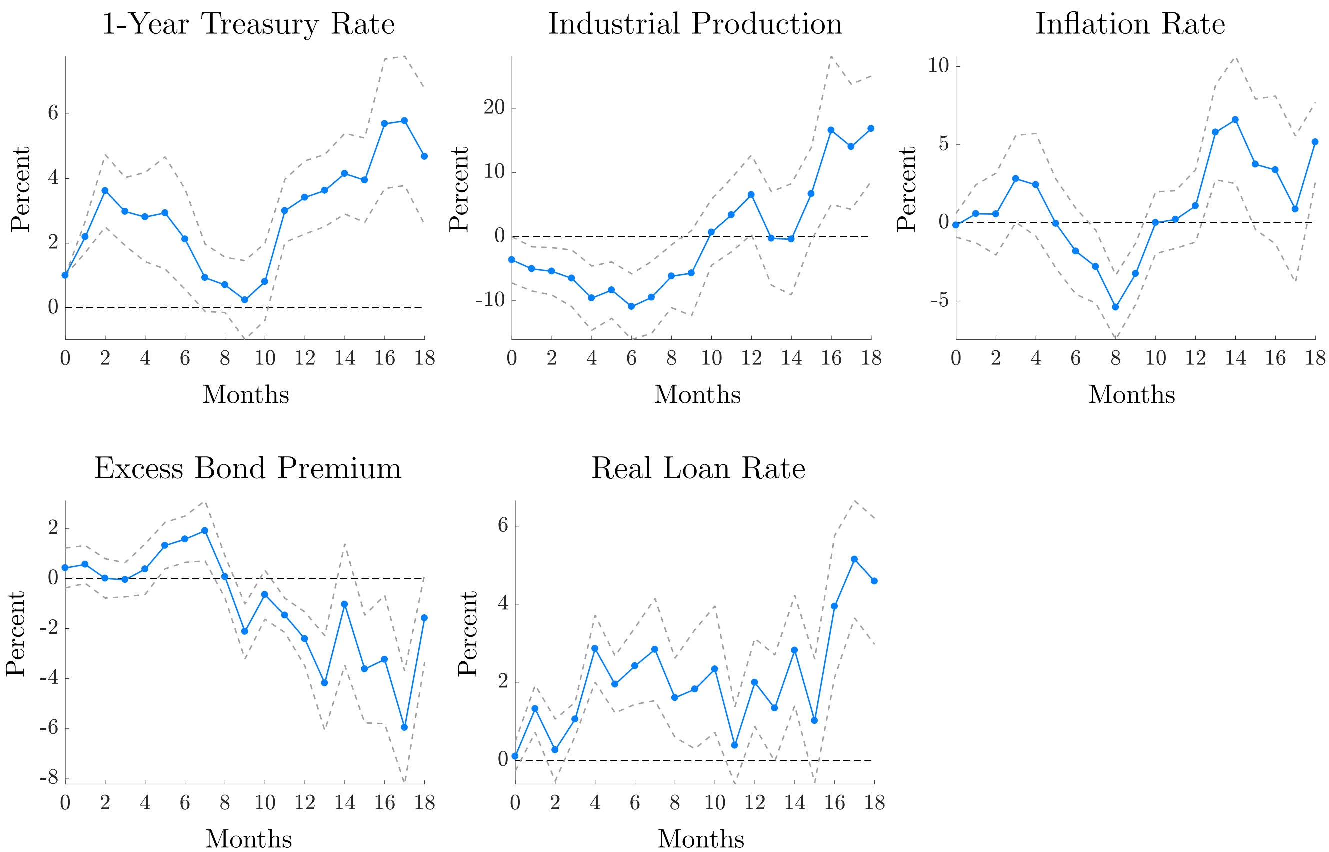

Figure C17. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the real loan rate, and the inflation expectation, estimated using Factor-Augmented LP-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the five main variables and the FRED-MD factors and 4-month lags of the instrument are included. Standard errors are calculated using the Newey-West heteroskedastic and autocorrelation consistent standard errors. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 6, and the heteroscedasticity-robust first-stage F-statistic is 14.5.

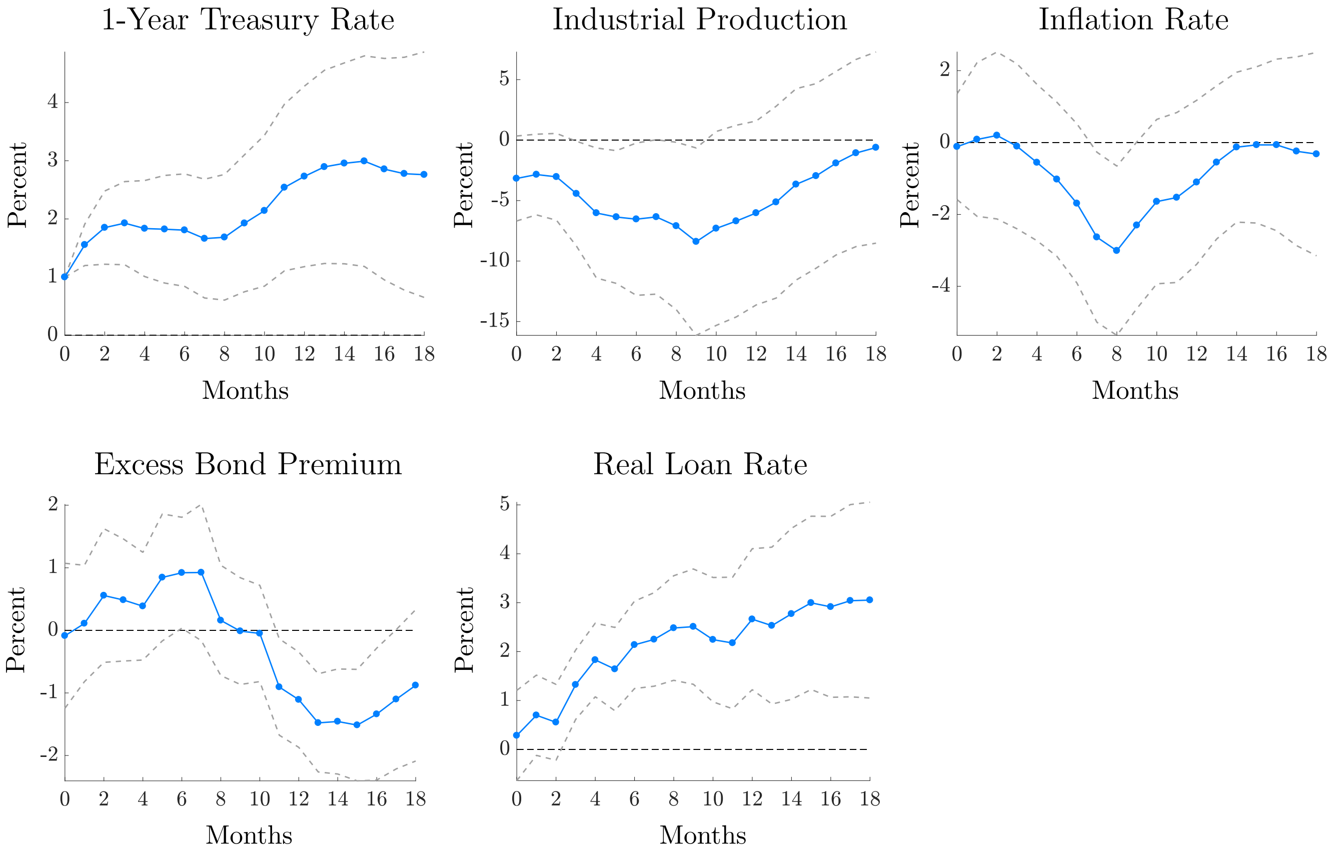

Figure C18. Response of the 1-year Treasury constant maturity rate, industrial production, inflation rate, the excess bond premium, the real loan rate, and the inflation expectation, estimated using SVAR-IV with unit effect normalization, during the post-TRACE period. Sample period: 2003:3–2016:12. 12-month lags of the five main variables and 4-month lags of the instrument are included. Standard errors are calculated using the sample variances computed from 1,000 draws from a parametric Gaussian bootstrap. Dashed lines are the 95% confidence interval. The first-stage F-statistic is 13.4, and the heteroscedasticity-robust first-stage F-statistic is 19.4.