Q-Monetary Transmission*

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Abstract

We study the transmission of monetary policy to corporate investment through policy-induced changes in Tobin's q. We provide identification and empirical evidence of this channel, develop a model of the economic mechanism, evaluate the ability of the quantitative theory to match the evidence, and assess the aggregate relevance of the channel in monetary transmission to investment.

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1. Introduction

The chain of causal links that lie between monetary policy actions and their ultimate effects on the macroeconomic variables is broadly referred to as *the monetary transmission mechanism*. Since the immediate effect of these policy actions is to influence a wide array of interest rates and prices of financial and non-financial assets, it is difficult to imagine many economic decisions that are not affected by monetary policy. Consequently, textbook treatments of the effects of monetary policy contain extensive taxonomies of a myriad of transmission mechanisms.[1] The broadest classification typically consists of three main transmission channels: the (*direct* or *traditional*) *interest-rate channel*, the *asset-price channel*, and the *credit channel*.

The *interest-rate channel* is best described as a *user-cost* or *real discount-rate channel*: Suppose there is an unexpected increase in the nominal policy rate, and that (as is usually the case) some of the increase passes through to real rates. Then, since the real rate is a key component of the user cost of capital, and the user cost of capital is a key determinant of the demand for capital (e.g., as in Jorgenson (1963)), investment should fall as a result of the monetary policy action.[2] The *asset-price channel* is best described as a *Tobin's q channel*: Suppose an unexpected increase in the nominal policy rate causes stock prices to fall (as is well documented empirically, e.g., Bernanke and Kuttner (2005)). Then the conventional q-theory of investment (e.g., Hayashi (1982)) implies real corporate investment should fall as a result of the monetary policy action. The *credit channel*, which includes the well-known *balance-sheet channel*, is best described as an amplification mechanism associated to the other two channels: Suppose an unexpected increase in the nominal policy rate causes asset prices to fall (e.g., through either of the previous two channels), which in turn deteriorates borrowers' net worth. Then the resulting increase in external finance premia (Bernanke and Gertler (1989)) or tightening of borrowing constraints (Kiyotaki and Moore (1997)) imply credit-financed investment should fall as a result of the monetary policy action.

The user-cost channel is well-studied, widely taught, and present in most quantitative models used in policy analysis. The credit channel has received much attention in the past decade, and is now standard in theoretical and quantitative policy-oriented modelling. The asset-price channel of monetary transmission was one of the key mechanisms that Tobin (1969) sought to

[1]See, e.g., Mishkin (1995, 1996, 2001), or Boivin et al. (2010).

[2]Our focus here is on corporate investment, but all these channels have obvious household counterparts for spending in consumption of durables and real estate.

model by introducing the famous q; it is described in undergraduate textbooks, and discussed in policy circles. There seems to be, however, essentially no academic research on this channel, either empirical or theoretical. In this paper we study the transmission of monetary policy to corporate investment through an asset-price channel activated by policy-induced changes in Tobin's q. We refer to this mechanism as *q-monetary transmission*. We provide empirical evidence of this channel, develop a model of the economic mechanism, evaluate the ability of the quantitative theory to match the evidence, and assess the aggregate relevance of the channel in monetary transmission to investment.

The main challenge for estimating the q-monetary transmission mechanism is that monetary policy can potentially affect firms' investment decisions and stock prices through other channels as well as indirect general equilibrium effects. For example, if a monetary shock lowers demand for a firm's output and this decreases profit, both the firm's investment and stock price may fall, but this does not imply that investment falls *because* the stock price falls. Similarly, a contractionary money shock may lower investment directly through the traditional user-cost channel, and the (anticipated) reduction of investment may lead to a reduction in the firm's stock price. The stock price is also likely to fall simply because of higher discounting of future dividends. But again, in this case the fall in the stock price is not *causing* the fall in investment. In the first example, both investment and the stock price are endogenous outcomes responding to the reduction in demand. In the second example, the stock price is responding to the interest-rate induced reduction in investment, and both drop due to higher discounting. Thus, we cannot hope to expose the causal relationship between q and investment that is inherent in the q-monetary transmission mechanism by simply estimating the comovement of investment and q induced by monetary shocks.

We meet this empirical challenge by exploiting the cross-sectional variation in the responses of stock prices to monetary shocks. Lagos and Zhang (2020b) provide evidence that stock turnover is a strong predictor of monetary policy passthrough to stock prices in the cross-section of U.S. publicly traded firms. Therefore, stock turnover can be used as a measure of the cross-sectional differences in the exposure of stock prices to monetary policy shocks. Given this, our empirical strategy builds on the idea that, if the cross-sectional variation in stock turnover is uncorrelated with other other sources of response-heterogeneity at the time of a monetary policy shock, then identified money shocks combined with heterogeneity in cross-sectional stock turnover can be used as a source of exogenous cross-sectional variation in Tobin's q. We then use this cross-sectional variation in the responses of stock prices to money shocks for firms with different stock turnover, to identify the effects of stock-price changes on firms' investment decisions. Specifically, based on this logic, we construct an instrument for the cross-sectional variation in Tobin's q by interacting monetary policy shocks with firm-specific stock turnover (calculated in the quarter prior to the shock). Our main exercise consists of estimating whether such instrumented variation in Tobin's q has significant effects on firms' equity issuance and investment behavior. We find it does.

Our work contributes to four literatures. First, we contribute to the literature on monetary transmission by filling the empirical and theoretical void around the asset-price channel that operates through Tobin's q. Second, we contribute to the empirical literature on investment by proposing a novel instrument for Tobin's q that can address the usual concerns related to the endogeneity of q in the standard q regressions (see, e.g., Hayashi and Inoue (1991), Blundell et al. (1992)). As mentioned above, our innovation is to construct an instrument by exploiting a combination of identified monetary policy shocks and the cross-sectional variation in stock price responses to these shocks. Third, our theoretical and empirical results on the response of firms' equity issuance to fluctuations in stock prices (induced by monetary shocks) contribute to the corporate finance literature that studies the relationship between firms' capital structure and macroeconomic conditions in general, and stock prices in particular (e.g., Baker and Wurgler (2002), Baker et al. (2003), Korajczyk and Levy (2003), Hovakimian et al. (2004), Gilchrist et al. (2005)). Fourth, we contribute to the literature that builds micro-founded models of monetary exchange to uncover new channels through which money affects macroeconomic outcomes (e.g., Lagos (2011), Lagos and Zhang (2015, 2019, 2020a,b), Rocheteau et al. (2018)).

The rest of the paper is organized as follows. Section 2 presents the basic model. Section 3 characterizes the main properties of the equilibrium. Section 4 considers a special case in which the equilibrium can be solved with paper and pencil to convey the main ideas. Section 5 contains the empirical analysis. In Section 6 we calibrate and simulate the model to assess the ability of the theory to fit the empirical evidence on the effects of monetary-policy induced changes in Tobin's q on equity issuance and investment. Finally, in Section 7 we employ our empirical estimates to provide a back-of-the-envelope evaluation of the aggregate relevance of the channel in monetary transmission to investment.

2. Model

Time is represented by a sequence of periods indexed by $t \in \{0, 1, ...\}$. Each time period is divided into two subperiods where different activities take place. There is a continuum of agents of three types: *investors*, each identified with a point in the set $\mathcal{I} = [0,1]$, *brokers*, each identified with a point in the set $\mathcal{B} = [0,1]$, and *entrepreneurs* (whom we will interchangeably refer to as *firms*), each identified with a point in the set $\mathcal{F} = [0,1]$. Brokers and investors are infinitely lived. Entrepreneurs live for a random number of periods: a fraction $1 - \pi \in [0,1]$ of the population of entrepreneurs who are alive at the beginning of the second subperiod of period t, dies (i.e., exits the economy) at the beginning of the second subperiod of period $t+1$. The set of entrepreneurs who die is a uniform random draw from the population of entrepreneurs, and each is immediately replaced by a newly born entrepreneur.

There are three commodities at each date: two consumption goods, called *good 1* and *good 2*, and a *capital* good. The consumption goods are perishable: good 1 and good 2 can only be consumed in the first and second subperiods, respectively. Capital is storable, but depreciates at rate $\delta \in [0,1]$ between periods. An entrepreneur $i \in \mathcal{F}$ born at time t enters the economy endowed with $\underline{K}_t^i \in \mathbb{R}_+$ units of capital and $w_t^i \in \mathbb{R}_+$ units of good 2. We assume that for each entrepreneur $i \in \mathcal{F}$, w_t^i is the realization of a nonnegative random variable distributed (independently over time and across entrepreneurs) with cumulative distribution function Ω_t. In the second subperiod of every period, investors and brokers are endowed with a resource called *labor (effort)* that they can use to produce good 2 one-for-one. There are two other production technologies that can be managed only by entrepreneurs. The first, uses capital available at the beginning of period t to produce good 1 in the first subperiod of period t. Specifically the capital stock K_t^i operated by an entrepreneur $i \in \mathcal{F}$ delivers $A_t^i K_t^i$ units of good 1 at the end of the first subperiod of t, where $A_t^i \in \mathbb{R}_{++}$ denotes the entrepreneur's idiosyncratic productivity. For each $i \in \mathcal{F}$, the process for $\left\{A_{t+1}^i\right\}_{t=0}^{\infty}$ is given by $A_{t+1}^i = \gamma_{t+1}^i A_t^i$, where γ_{t+1}^i is a nonnegative random variable with cumulative distribution function Ξ, i.e., $\Pr(\gamma_{t+1}^i \le \gamma) = \Xi(\gamma)$, and mean $\bar{\gamma}^i$. The initial condition for the productivity of entrepreneur $i \in \mathcal{F}$ who enters the economy at time t, denoted $\underline{A}_t^i$, is a random draw from the distribution of productivities among existing entrepreneurs. The second production technology can be operated by an entrepreneur in the second subperiod of period t, and uses good 2 and the capital the entrepreneur has in place at the beginning of period t to augment the capital that the entrepreneur will have in place to produce good 1 in period $t+1$. Formally, this technology is represented by a cost function, $C\left(I_t, K_t^i\right) \equiv I_t + \Phi\left(I_t/K_t^i\right) K_t^i$, interpreted as the cost (in terms of good 2) of producing and installing I_t units of capital for an entrepreneur $i \in \mathcal{F}$ whose current capital is K_t^i. We assume $0 < \Phi''$, and that there is a $\delta_0 \in \mathbb{R}_+$ such that $\Phi(\delta_0) = \Phi'(\delta_0) = 0$. Once installed, capital is entrepreneur-specific, i.e., capital installed by entrepreneur i is only productive when operated by entrepreneur i.

The asset structure is as follows. In the second subperiod of every period, in order to finance the cost of investing in new capital, every entrepreneur can issue identical, durable, and perfectly divisible equity claims (or *shares*) to the future returns from the newly created capital. (Entrepreneurs are also allowed to sell equity claims on any existing capital they currently own.) A share issued by entrepreneur i in the second period of t, represents ownership of 1 unit of capital along with the stream of *dividends* of good 1 produced by that unit of capital managed by entrepreneur i, i.e., $\{A_{t+1}^i\}_{t=0}^{\infty}$. When an entrepreneur dies, the outstanding equity claims she had previously issued disappear, and the underlying capital plus any capital or financial assets or claims owned by the entrepreneur are distributed uniformly (lump sum) to the cohort of newly born entrepreneurs. There are two other financial instruments: a one-period real pure-discount government *bond*, and *money*. A unit of the bond issued in the second subperiod of t represents a risk-free claim to one unit of good 2 in the second subperiod of $t+1$. The stock of bonds outstanding at time t is B_t, and all private agents take the sequence $\{B_t\}_{t=0}^{\infty}$ as given. Money is intrinsically useless (it is not an argument of any utility or production function, and unlike equity or bonds, money does not constitute a formal claim to any resources). The money supply at the beginning of period t is denoted M_t, and we assume $M_{t+1} = \mu M_t$, with $\mu \in \mathbb{R}_{++}$ and $M_0 \in \mathbb{R}_{++}$ given. The government injects or withdraws money via lump-sum transfers or taxes to investors in the second subperiod of every period. At the beginning of period $t=0$, each investor is endowed with an equal portfolio of money. We assume brokers do not hold financial assets (money, bonds, or equity).[3]

The market structure is as follows. In the second subperiod of every period, all agents can trade good 2, labor services, equity shares, bonds, and money, in a spot Walrasian market.[4] In

[3]This assumption allows us to abstract from the broker's portfolio problem in the first subperiod, which is not essential for the questions we study in this paper. See Lagos and Zhang (2015, 2020b) for a treatment of the broker's portfolio problem.

[4]Notice that equity shares (i.e., the claims on installed capital and its returns) can be traded freely, but the actual physical capital created and installed by a particular entrepreneur is assumed to be non tradable. The idea is that, once installed by an entrepreneur, physical capital becomes entrepreneur-specific and cannot be

the first subperiod of every period, investors can trade equity shares and money in a random bilateral *over-the-counter (OTC) market* with brokers, while brokers can also trade equity shares and money with other brokers in a spot Walrasian *interbroker market.* We use $\alpha \in [0,1]$ to denote the probability that an individual investor is able to make contact with a broker in the OTC market. Once a broker and an investor have contacted each other, the pair negotiates the quantity of equity shares and money that the broker will trade in the interdealer market on behalf of the investor, and a fee for the broker's intermediation services. The terms of the trade between an investor and a broker in the OTC market are determined by Nash bargaining, where $\theta \in [0,1]$ is the investor's bargaining power. We assume the fee is negotiated in terms of good 2, and paid at the beginning of the following subperiod.[5] The timing is that the round of OTC trade takes place in the first subperiod and ends before equity pays out first-subperiod dividends.[6] Equity purchases in the OTC market cannot be financed by borrowing (e.g., due to anonymity and lack of commitment and enforcement). This assumption and the structure of preferences described below create the need for a medium of exchange in the OTC market.[7]

An individual broker's preferences are given by

$$\mathbb{E}_0^B \sum_{t=0}^{\infty} \beta^t (c_t - h_t),$$

where $\beta \in (0,1)$ is the discount factor, and c_t and h_t denote a broker's consumption of good 2, and utility cost from supplying h_t units of labor in the second subperiod of period t, respectively. The expectation operator, $\mathbb{E}_0^B$, is with respect to the probability measure induced by the random trading process in the OTC market. Dealers get no utility from the dividend good.[8] An individual investor's preferences are given by

$$\mathbb{E}_0^I \sum_{t=0}^{\infty} \beta^t \left(c_t - h_t + \varepsilon_t y_t\right),$$

operated by another entrepreneur. An entrepreneur can, however, disinvest (which entails bearing the investment adjustment cost, Φ) to turn installed capital into good 2, which can then be traded freely in the Walrasian market. Similarly, when the entrepreneur dies, the quantity of good 2 obtained from unistalling the capital that the entrepreneur used to manage (net of adjustment costs) is distributed to newly born entrepreneurs.

[5] This is the specification used in Lagos and Zhang (2020b). Lagos and Zhang (2015) instead assume the investor must pay the intermediation fee to the broker on the spot (with money or equity). The timing convention in Lagos and Zhang (2020b) simplifies the exposition without affecting the mechanisms of interest.

[6] As in previous search models of OTC markets, e.g., Duffie et al. (2005) and Lagos and Rocheteau (2009), an investor must own the equity in order to consume the dividend flow of consumption good in the OTC round.

[7] See Lagos and Zhang (2020a, 2019) for a similar model where investors can buy equity *on margin*.

[8] This assumption implies that dealers have no direct consumption motive for holding the equity share. It is easy to relax, but we adopt it because it is the standard benchmark in the search-based OTC literature, e.g., see Duffie et al. (2005), Lagos and Rocheteau (2009), Lagos et al. (2011), and Weill (2007).

where c_t and h_t denote an investor's consumption of good 2, and utility cost from supplying h_t units of labor in the second subperiod of period t, respectively, and y_t is the investor's consumption of good 1 at the end of the first subperiod of period t. The variable ε_t denotes the realization of an idiosyncratic valuation shock that is distributed independently over time and across investors, with a differentiable cumulative distribution function G on the support $[\varepsilon_L, \varepsilon_H] \subseteq [0, \infty]$, and $\bar{\varepsilon} = \int \varepsilon dG(\varepsilon)$. An investor learns the realization ε_t at the beginning of the first subperiod of period t, immediately before the OTC trading round. The expectation operator, $\mathbb{E}_0^I$, is with respect to the probability measure induced by the randomness in the dividend process, the investor's valuation shocks, and the trading process in the OTC market.

The preferences of an entrepreneur born in the second subperiod of t are given by

$$\mathbb{E}_t \sum_{j=t}^{\infty} (\beta\pi)^{(j-t)} (c_j + \beta\varepsilon_E y_{j+1}),$$

where c_j is the consumption of good 2 in the second subperiod of period j, and y_{j+1} is the entrepreneur's consumption of good 1 at the end of the first subperiod of period $j+1$, with $\varepsilon_E > 0$ a fixed parameter. The expectation operator, $\mathbb{E}_t$, is with respect to the probability measure induced by the random idiosyncratic productivity process.

3. Equilibrium

Consider the determination of the terms of trade in a bilateral meeting in the OTC round of period t between a broker and an investor with valuation ε and portfolio $\boldsymbol{a}_t = (m_t, \boldsymbol{s}_t)$, with $\boldsymbol{s}_t = \left[s_t^i\right]_{i\in\mathcal{F}}$, where m_t denotes money holdings and s_t^i denotes holdings of shares issued by firm $i \in \mathcal{F}$. Let $W_t(\boldsymbol{a}_t, \varphi_t)$ denote the maximum expected discounted payoff at the beginning of the second subperiod of period t of an investor who is holding portfolio $\boldsymbol{a}_t$ and has to pay a broker fee φ_t. Let $[\overline{\boldsymbol{a}}_t(\boldsymbol{a}_t, \varepsilon), \varphi_t(\boldsymbol{a}_t, \varepsilon)]$ represent the bargaining outcome for a bilateral trade at time t between a broker and an investor with portfolio $\boldsymbol{a}_t$ and valuation ε, with $\overline{\boldsymbol{a}}_t(\boldsymbol{a}_t, \varepsilon) = (\overline{m}_t(\boldsymbol{a}_t, \varepsilon), \overline{\boldsymbol{s}}_t(\boldsymbol{a}_t, \varepsilon))$, where $\overline{\boldsymbol{s}}_t(\boldsymbol{a}_t, \varepsilon) = [\overline{s}_t^i(\boldsymbol{a}_t, \varepsilon)]_{i\in\mathcal{F}}$. Then, $[\overline{\boldsymbol{a}}_t(\boldsymbol{a}_t, \varepsilon), \varphi_t(\boldsymbol{a}_t, \varepsilon)]$ is the solution to

$$\max_{\overline{m}_t, [\overline{s}_t^i]_{i\in\mathcal{F}}, \varphi_t} \left[\varepsilon\bar{\mathrm{Y}}_t + W_t(\tilde{\boldsymbol{a}}_t, \varphi_t) - \varepsilon\mathrm{Y}_t - W_t(\boldsymbol{a}_t', 0)\right]^{\theta} [\varphi_t]^{1-\theta} \qquad (1)$$

$$
\begin{aligned}
\text{s.t. } \overline{m}_t + \int_{i\in\mathcal{F}} p_t^i \bar{s}_t^i di &\leq m_t + \int_{i\in\mathcal{F}} p_t^i s_t^i di \\
\varepsilon \mathrm{Y}_t + W_t(\boldsymbol{a}_t', 0) &\leq \varepsilon \bar{\mathrm{Y}}_t + W_t\left(\tilde{\boldsymbol{a}}_t, \varphi_t\right) \\
\bar{\mathrm{Y}}_t &= \int_{i\in\mathcal{F}} A_t^i \bar{s}_t^i di \\
\mathrm{Y}_t &= \int_{i\in\mathcal{F}} A_t^i s_t^i di \\
\tilde{\boldsymbol{a}}_t &\equiv (\overline{m}_t, [\pi \bar{s}_t^i]_{i\in\mathcal{F}}) \\
\boldsymbol{a}_t' &\equiv (m_t, [\pi s_t^i]_{i\in\mathcal{F}}) \\
\overline{m}_t, \bar{s}_t^i, \varphi_t &\in \mathbb{R}_+ \text{ for all } i \in \mathcal{F},
\end{aligned}
$$

where p_t^i is the dollar price of an equity share of firm i in the interbroker market of period t. The first and second constraints are the investor's budget, and participation constraints, respectively.

Let $V_t\left(\boldsymbol{a}_t, \varepsilon\right)$ denote the maximum expected discounted payoff of an investor with valuation ε and portfolio $\boldsymbol{a}_t$ at the beginning of the OTC round of period t. In the second subperiod of period t, let ϕ_t be the real price of money, ψ_t^i be the real price of a share of firm $i \in \mathcal{F}$, and ϕ_t^b be the real price of the government bond (all expressed in terms of the good 2). Then,

$$
W_t\left(\boldsymbol{a}_t, \varphi_t\right) = \max_{c_t, h_t, \boldsymbol{a}_{t+1}} \left[c_t - h_t + \beta \int V_{t+1}\left(\boldsymbol{a}_{t+1}, \varepsilon\right) dG(\varepsilon)\right] \tag{2}
$$

$$
\begin{aligned}
\text{s.t. } c_t + \phi_t m_{t+1} + \phi_t^b b_{t+1} + \int_{i\in\mathcal{F}} \psi_t^i s_{t+1}^i di &\leq h_t + \phi_t m_t + b_t + \int_{i\in\mathcal{F}} \psi_t^i s_t^i di - \varphi_t + T_t \\
\boldsymbol{a}_{t+1} &\equiv (m_{t+1}, b_{t+1}, [s_{t+1}^i]_{i\in\mathcal{F}}) \\
c_t, h_t, m_{t+1}, b_{t+1}, s_{t+1}^i &\in \mathbb{R}_+, \text{ for all } i \in \mathcal{F},
\end{aligned}
$$

where c_t denotes consumption of good 2, and $T_t \in \mathbb{R}$ is the real value of the time t lump-sum monetary transfer. The value function of an investor who enters the OTC round of period t with portfolio $\boldsymbol{a}_t$ and valuation ε is

$$
\begin{aligned}
V_t\left(\boldsymbol{a}_t, \varepsilon\right) = \; & \alpha \left\{\varepsilon \bar{\mathrm{Y}}_t(\boldsymbol{a}_t, \varepsilon) + W_t\left[\tilde{\boldsymbol{a}}_t\left(\boldsymbol{a}_t, \varepsilon\right), \varphi_t\left(\boldsymbol{a}_t, \varepsilon\right)\right]\right\} \\
& + (1-\alpha)\left[\varepsilon \mathrm{Y}_t(\boldsymbol{a}_t, \varepsilon) + W_t\left(\boldsymbol{a}_t'\left(\boldsymbol{a}_t, \varepsilon\right), 0\right)\right],
\end{aligned} \tag{3}
$$

where

$$\begin{aligned}
\bar{\mathrm{Y}}_t(\boldsymbol{a}_t,\varepsilon) &\equiv \int_{i\in\mathcal{F}} A_t^i \bar{s}_t^i(\boldsymbol{a}_t,\varepsilon)\,di \\
\tilde{\boldsymbol{a}}_t(\boldsymbol{a}_t,\varepsilon) &\equiv \left(\overline{m}_t(\boldsymbol{a}_t,\varepsilon), b_t, \left[\pi\bar{s}_t^i(\boldsymbol{a}_t,\varepsilon)\right]_{i\in\mathcal{F}}\right) \\
\mathrm{Y}_t(\boldsymbol{a}_t,\varepsilon) &\equiv \int_{i\in\mathcal{F}} A_t^i s_t^i di \\
\boldsymbol{a}_t'(\boldsymbol{a}_t,\varepsilon) &\equiv (m_t, b_t, [\pi s_t^i]_{i\in\mathcal{F}}).
\end{aligned}$$

Let $J_t^i\left(b_t, K_t^i, S_t^i, A_t^i\right)$ denote the maximum expected discounted payoff at the beginning of the second subperiod of period t of an entrepreneur $i\in\mathcal{F}$ who was alive at time $t-1$, and who currently has bond holding b_t, installed capital K_t^i, outstanding equity claims S_t^i, and productivity A_t^i. Then,

$$\begin{aligned}
J_t^i\left(b_t, K_t^i, S_t^i, A_t^i\right) = \max_{c_t,b_{t+1},I_t,E_t} &\Big\{c_t + \beta\mathbb{E}_t\Big[\varepsilon_E A_{t+1}^i(K_{t+1}^i - S_{t+1}^i) \\
&+\pi J_{t+1}^i\left(b_{t+1}, K_{t+1}^i, S_{t+1}^i, A_{t+1}^i\right)\Big]\Big\}
\end{aligned} \tag{4}$$

$$\begin{aligned}
\text{s.t. } c_t + C\left(I_t, K_t^i\right) + \phi_t^b b_{t+1} &\leq \psi_t^i E_t + b_t \\
K_{t+1}^i &= (1-\delta)K_t^i + I_t \\
S_{t+1}^i &= (1-\delta)S_t^i + E_t \\
S_{t+1}^i &\leq K_{t+1}^i \\
c_t, b_{t+1}, K_{t+1}^i, S_{t+1}^i &\in \mathbb{R}_+,
\end{aligned}$$

where c_t denotes consumption of good 2, I_t is the quantity of good 2 invested to produce new capital (net of the installation cost), E_t is the number of newly issued equity shares, and $A_{t+1}^i = \gamma_{t+1}^i A_t^i$. The value function for a newly born entrepreneur $i\in\mathcal{F}$ who enters the economy in the second subperiod of period t is $J_t^i\left(w_t^i, \underline{K}_t^i, 0, \underline{A}_t^i\right)$, where $\underline{K}_t^i$ is the initial capital endowment, w_t^i is the realization of the initial endowment of good 2, and $\underline{A}_t^i$ is the realization of the initial productivity draw.

4. An analytical example

Assume $\pi = 0$, i.e., entrepreneurs live for one period, and $A_t^i = A^i \in \mathbb{R}_{++}$ for all t and $i\in\mathcal{F}$. Then, for a firm i that enters the economy in the second subperiod of t with initial conditions

w_t^i and $\underline{K}_t^i$, (4) specializes to

$$J_t^i\left(w_t^i, \underline{K}_t^i, 0, A^i\right) = \max_{c_t, I_t, S_{t+1}^i} \left[c_t + \beta\varepsilon_E A^i (K_{t+1}^i - S_{t+1}^i)\right] \tag{5}$$

$$\begin{aligned} \text{s.t. } c_t + C\left(I_t, \underline{K}_t^i\right) &\leq \psi_t^i S_{t+1}^i + w_t^i \\ K_{t+1}^i &= (1-\delta)\,\underline{K}_t^i + I_t \\ c_t, K_{t+1}^i, S_{t+1}^i &\in \mathbb{R}_+ \\ S_{t+1}^i &\leq K_{t+1}^i \end{aligned}$$

For what follows, let $\partial C(I,K)/\partial I \equiv C_1(I/K)$, and for any $x \in \mathbb{R}_+$, let $\iota(x)$ denote the unique number, ι, that solves $C_1(\iota) = x$. For any $\iota \in \mathbb{R}$, it is also convenient to define $\text{C}(\iota) \equiv \iota + \Phi(\iota)$. Notice this allows us to write $C(\iota K, K) = \text{C}(\iota)\,K$. Also, the maintained assumptions $\Phi(\delta_0) = \Phi'(\delta_0) = 0 < \Phi''(\cdot)$ imply that if $\delta_0 = 0$, then $\text{C}(0) = \text{C}'(0) = 0 < \text{C}''(\cdot)$, and $\text{C}'(\iota) > 0$ for all $\iota > 0$.

Proposition 1. *Assume* $\delta_0 = 0$*, so* $C\left(0, K_t^i\right) = 0$ *and* $C_1(0) = 1$*. Also, assume* $0 < w_t^i$ *and* $\delta = 1 < \beta\varepsilon_E A^i$*. Let* I_t^**,* S_{t+1}^{i*}*, and* c_t^* *denote the consumption, investment, and equity issuance that solve (5), and let* $\tilde{\psi}^i \equiv \beta\varepsilon_E A^i$*,* $\iota_t^i \equiv \iota(\psi_t^i)$*, and* $\tilde{\iota}^i \equiv \iota(\tilde{\psi}^i)$*. Then: (i) If* $\tilde{\psi}^i \leq \psi_t^i$*,*

$$\begin{aligned} I_t^* &= \iota_t^i \underline{K}_t^i \\ S_{t+1}^{i*} &= \begin{cases} \iota_t^i \underline{K}_t^i & \text{if } \tilde{\psi}^i < \psi_t^i \\ \left[\max\left(\frac{\text{C}(\iota_t^i)\underline{K}_t^i - w_t^i}{\psi_t^i}, 0\right), \iota_t^i \underline{K}_t^i\right] & \text{if } \tilde{\psi}^i = \psi_t^i \end{cases} \\ c_t^* &= w_t^i + \psi_t^i S_{t+1}^{i*} - \text{C}(\iota_t^i)\underline{K}_t^i. \end{aligned}$$

(ii) If $\psi_t^i < \tilde{\psi}^i$*,*

$$\begin{aligned} I_t^* &= \begin{cases} \tilde{\iota}^i \underline{K}_t^i & \text{if } \text{C}(\tilde{\iota}^i)\underline{K}_t^i \leq w_t^i \\ \text{C}^{-1}(w_t^i/\underline{K}_t^i) & \text{if } \text{C}(\iota_t^i)\underline{K}_t^i \leq w_t^i < \text{C}(\tilde{\iota}^i)\underline{K}_t^i \\ \iota_t^i \underline{K}_t^i & \text{if } w_t^i < \text{C}(\iota_t^i)\underline{K}_t^i \end{cases} \\ S_{t+1}^{i*} &= \begin{cases} 0 & \text{if } \text{C}(\tilde{\iota}^i)\underline{K}_t^i \leq w_t^i \\ 0 & \text{if } \text{C}(\iota_t^i)\underline{K}_t^i \leq w_t^i < \text{C}(\tilde{\iota}^i)\underline{K}_t^i \\ \frac{\text{C}(\iota_t^i)\underline{K}_t^i - w_t^i}{\psi_t^i} & \text{if } w_t^i < \text{C}(\iota_t^i)\underline{K}_t^i \end{cases} \\ c_t^* &= \begin{cases} w_t^i - \text{C}(\tilde{\iota}^i)\underline{K}_t^i & \text{if } \text{C}(\tilde{\iota}^i)\underline{K}_t^i \leq w_t^i \\ 0 & \text{if } \text{C}(\iota_t^i)\underline{K}_t^i \leq w_t^i < \text{C}(\tilde{\iota}^i)\underline{K}_t^i \\ 0 & \text{if } w_t^i < \text{C}(\iota_t^i)\underline{K}_t^i. \end{cases} \end{aligned}$$

In Proposition 1, $\tilde{\psi}^i$ is the marginal private value to entrepreneur i of investing capital, while ψ_t^i can be interpreted as the marginal value of investment to an outside investor who is pricing firm i's equity. Part (i) focuses on the case in which outside investors value the marginal investment in capital more than the entrepreneur. In this case, the entrepreneur choose the scale of investment, I_t^*, so that the marginal cost, $C_1\left(I_t^*/\underline{K}_t^i\right)$ equals the marginal value of the investment to the outside investor, ψ_t^i. Moreover, the investment is financed entirely by equity issuance, i.e., $S_{t+1}^{i*} = I_t^*$ (in the knife-edge case with $\tilde{\psi}^i = \psi_t^i$, where the entrepreneur is indifferent between financing by equity issuance or out of her own funds, w_t^i).

Part (ii) of Proposition 1 focuses on the case in which the entrepreneur values the marginal investment in capital more than outside investors, i.e., $\psi_t^i < \tilde{\psi}^i$. In this case, the investment, financing, and consumption decisions of the entrepreneur depend not only her valuation and the outside investors' valuation of investment, but also on the entrepreneur's own wealth, w_t^i. First, if the entrepreneur's wealth is high enough, i.e., $\mathrm{C}(\tilde{\iota}^i)\underline{K}_t^i \leq w_t^i$, then the entrepreneur is financially unconstrained: she chooses the first-best investment rate, $\tilde{\iota}^i$ (the one that equates the marginal cost of investment to her own marginal valuation, $\tilde{\psi}^i$), finances it entirely with own funds, i.e., $S_{t+1}^{i*} = 0$, and consumes the unspent funds, i.e., sets $c_t^* = w_t^i - \mathrm{C}\left(\tilde{\iota}^i\right)\underline{K}_t^i$. Second, if the entrepreneur's own wealth is very low, specifically $w_t^i < \mathrm{C}(\iota_t^i)\underline{K}_t^i$, i.e., lower than what would be needed to self-finance the level of investment that would be chosen based on outside investors' marginal valuation of investment, ψ_t^i, then she chooses to invest the quantity that equates the marginal cost of investment to the marginal valuation of outside investors, i.e., $\iota_t^i\underline{K}_t^i$, uses up all of her own funds (sets $c_t^* = 0$), and also resorts to equity issuance. Third, if the entrepreneur's wealth is too low to self-finance the first best but not too low to self-finance the level that would be chosen based on outside investor's valuations, i.e., if $\mathrm{C}(\iota_t^i)\underline{K}_t^i \leq w_t^i < \mathrm{C}(\tilde{\iota}^i)\underline{K}_t^i$, then the entrepreneur invests the maximum that can be financed with own funds, i.e., the quantity I_t^* that satisfies $\mathrm{C}(I_t^*)\underline{K}_t^i = w_t^i$, sets $c_t^* = 0$, and issues no equity.

The main takeaway from Proposition 1 is that investment and equity issuance will generally respond to the market price of equity. For firms run by entrepreneurs who assign a lower value to investment than the market, as in part (i) of the proposition, the relationship is simple: higher stock prices induce these firms to invest and issue equity to finance the investment. For firms run by entrepreneurs who assign a higher value to investment than the market, as in part (ii) of the proposition, the relationship is more nuanced: only firms whose own "liquid" funds, i.e., funds available to finance investment, are relatively low will increase investment and equity issuance when the market price of equity increases. In the following section we take these theoretical predictions to the data.

5. Empirics

5.1. Data

We follow the literature that employs high-frequency movements in financial markets around Federal Open Market Committee (FOMC) press releases to isolate unexpected components of monetary policy announcements from endogenous responses to macroeconomic conditions.[9] A conventional way to do this is by measuring changes in rates implied by federal funds futures contracts in narrow 30-minute windows around policy announcement times. Given that futures contracts capture market participants' expectations about interest rates, these changes provide a proxy for exogenous policy rate shocks. The identification assumption is that in the narrow window around the press release there are no other, non-monetary shocks affecting futures rates.

Earlier work has pointed out that the unexpected component of monetary policy decisions as measured by the high-frequency movements in federal funds futures rates may nontheless contain additional information about the conduct of monetary policy, such as the implicit revelation of the monetary authority's information about economic fundamentals imperfectly observed by the private sector.[10] Treating these measures as purely exogenous changes in policy rates may thus lead to further imprecisions in inference. To address this issue, we also consider as a monetary shock proxy the series implied by the method of Jarociński and Karadi (2019).[11] Yet because the identification approach by Jarociński and Karadi (2019) infers a purged shock proxy series using a VAR model, it introduces further uncertainty in the proxy series due to uncertainty about the VAR parameters. To abstract from potential complications introduced by generated instruments and VAR misspecification for our inference based on non-linear panel local projections, we construct our baseline shock proxy series based on the raw, high-frequency changes in 3-month ahead federal funds futures contracts at FOMC

[9] Prominent early examples of such an event study based approach to the effects of monetary policy are Kuttner (2001), Cochrane and Piazzesi (2002), Bernanke and Kuttner (2005), Gürkaynak et al. (2005).

[10] See, for example, Nakamura and Steinsson (2018), Miranda-Agrippino and Ricco (2019), and Jarociński and Karadi (2019).

[11] Their proposed approach employs a structural vector autoregression (VAR) model identified using high-frequency changes in federal funds futures rates alongside sign restrictions imposing that conventional monetary policy shocks generate opposite-signed surprises in futures rates and returns in the S&P500 index. This purges the proxy series from informational components that generate positive high-frequency comovement between interest rates and stock returns.

announcement times. And we consider alternative shock series following Jarociński and Karadi (2019) in robustness analysis.

Given that we work with quarterly firm-level data, we add up the high-frequency changes in the federal funds futures rate by quarter to arrive at our quarterly series of monetary policy shock proxies denoted as ε_t^m. While we acknowledge that ε_t^m is still very likely a noisy measure of true, fundamental monetary shocks and should be applied as an instrument in IV regressions (Stock and Watson, 2018), we will treat ε_t^m simply as a measure of monetary shocks in our reduced form specifications. In our main empirical IV specifications, we use ε_t^m in the construction of an instrument for stock prices. We use the convention that a positive ε_t^m stands for an unexpected increase in interest rates, and thus a contractionary monetary shock.

Our firm-level data comes from the Center for Research in Security Prices (CRSP) and Compustat databases. We use daily time series for all individual common stocks available in the CRSP database. As a measure of trade volume for each stock, we construct the daily *turnover rate* as the ratio of trade volume (total number of shares traded) to the number of outstanding shares, for any given day. After averaging each stock's daily turnover rates by quarter, we merge the resulting quarterly turnover series (denoted x_t^i for firm i quarter t below) with the corresponding firm fundamentals from the quarterly Compustat universe of publicly listed U.S. incorporated non-financial firms.

The key objects of interest from the Compustat database are measures of q, firms' equity issuances, and investment rates. As our measure of q, we employ the market-to-book ratio, i.e. an *average* q, computed as the book value of total assets plus the market value of common equity minus the book value of common equity, scaled by the book value of total assets, or $q = 1 + \frac{\text{MV equity}-\text{BV equity}}{\text{book total assets}}$. Moreover, as Eberly et al. (2012), we use the natural logarithm of q in our estimated regressions. Doing so provides a better fit, improving the precision of our estimates due to skewness in the firm-level data, while not affecting the qualitative implications. As the measure of *equity issuances* (denoted E_t^i), we employ the net measure of Compustat reported sales of equity minus purchases of equity in quarter t. We normalize the net issuances by one quarter lagged total balance sheet size (denoted B_{t-1}^i). As the main measure of *investment*, we use the Compustat reported capital expenditures variable (denoted I_t^i). We normalize the investment measures with Compustat's lagged net property plant and equipment (denoted K_{t-1}^i).[12] In robustness analysis, we also employ measures of firms' *size*,

[12]Notice the slight discrepancy in the time-indexation of K^i compared to the theoretical model setup. In the

age, *leverage* and *liquidity ratios* as additional controls.[13]

Our sample covers the period 1990Q1–2016Q4, for which high-frequency data on federal funds futures is available.[14] Because our regression specifications include simple firm fixed effects in a dynamic panel setting, we only include data from firms which are observed for at least 40 uninterrupted quarters at any point during the sample period. Appendix B.1 discusses sample selection and data construction in more detail.

5.2. Identification through turnover heterogeneity

In line with a model of monetary exchange in equity markets, analogous to the model presented above, Lagos and Zhang (2020b) provide evidence using daily data that stock turnover in the four weeks prior to a monetary policy announcement is a strong predictor of policy pass-through to stock prices in the cross-section of U.S. public firms. Stock turnover can thus be considered as a measure of firms' stock price exposure to monetary policy shocks.

If the variation in turnover were assigned randomly across firms, in a manner uncorrelated with any firm characteristics or fundamentals at the time of a monetary policy shock, then identified policy shocks combined with cross-sectional turnover heterogeneity can be used as a source of exogenous cross-sectional variation in stock prices and Tobin's q. And this cross-sectional variation in stock price responses for high- versus low-turnover firms can then in turn be applied to identify the effects of stock price fluctuations on firms' decisions.

The focus on cross-sectional variation is important because monetary policy shocks can affect the levels of all stock prices and firms' choices, potentially through intricate general equilibrium effects. For example, by lowering demand for the firm's production and decreasing profits, a contractionary monetary shock can cause stock prices and investment to fall. But it is not necessarily the case that investment falls *because* the stock price falls. Rather, both are endogenous outcomes responding to a worsening of demand. Thus, by simply observing the comovements of q and investment in the aftermath of monetary shocks, one cannot hope to

empirical work, we denote the capital stock in place at the end of $t-1$ as K^i_{t-1} to emphasize the quarter in which it is reported in Compustat. The corresponding object in the theoretical model setup is "K^i_t". In robustness tests, we verify that our main results are not driven by any specific method of construction of investment or capital stock data and also hold when inferring the K^i_t series based on a conventional perpetual inventory method, and when measuring I^i_t as net investment equaling the quarterly difference in this K^i_t.

[13] For constructing a measure of firm age, we follow the approach of Cloyne et al. (2018) and use data from Thomson Reuters' WorldScope database to infer time since the firm's incorporation.

[14] In constructing our various measures of ε^m_t, we employ the dataset used by Jarociński and Karadi (2019), in turn based on an updated version of the Gürkaynak et al. (2005) dataset.

make any causal statements.[15]

Based on the logic above, we construct an instrument for the cross-sectional variation in Tobin's q by interacting monetary policy shocks and individual stock turnover in the quarter prior to the shock. The focus on cross-sectional variation is ensured by considering regression specifications in which time-specific fixed effects pick up any direct and general equilibrium effects common across all firms. And our exercise of main interest is to assess whether such instrumented variation in q predicts firms' equity issuance and investment behavior. In order for such IV estimates to have a causal interpretation in measuring the effect stock prices on firms' choices, the following identification assumption must hold: firms with different stock turnover respond to monetary policy shocks differently only because of differences in their stock price responses to the shocks.

If stock turnover was truly assigned randomly immediately prior to the realization of monetary shocks, the identification assumption for causality would be satisfied. The fact that this is unlikely to be the case in reality, leads to potential concerns in the validity of a causal interpretation of our estimates. The randomness of variation in stock turnover could be violated in either of two main ways:

1. Certain firm characteristics cause their stocks to be traded relatively more or less. For example, the stocks of bigger firms may provide a more liquid market and invite higher trading activity, even relative to their potentially large market capitalizations.

2. For reasons not related to firm characteristics, stocks may experience heterogeneous trading activity. As suggested by the model, this can lead to differences in stock prices which in turn can affect firm behavior, for example their financing or portfolio decisions.

Either of these phenomena can introduce covariance between certain firm characteristics and stock turnover. If these characteristics are in turn predictive of firms' responsiveness to monetary policy shocks in their own right due to other channels, as for example leverage could (Anderson and Cesa-Bianchi, 2020), then any heterogeneous behavior predicted by turnover alone could instead be explained by reasons other than heterogeneous stock price changes, violating the identification assumption for causality. We address these concerns in robustness analysis by allowing various other firm-level controls to explain heterogeneous responsiveness

[15]More formally, one can think of exploring such comovements by regressing investment on q, instrumenting the latter with identified monetary policy shocks.

of equity issuance and investment in addition to turnover. In addressing point 1. above, we introduce measures of firm size and age, and regarding 2., we also include measures of leverage and liquid asset holdings.

For our approach in instrumenting Tobin's q to plausibly provide evidence of the effects of q on firms' choices, we should observe that firms with different stock turnover exhibit heterogeneous responsiveness to monetary shocks both in q and in their behavior. We first explore whether this is true by estimating 'reduced form' OLS regressions. Having established whether and when firms with higher turnover also exhibit differential equity issuance and investment responses, we move to the instrumental variables regressions of main interest.

5.3. Reduced form regressions

Our empirical analysis builds on local projections in the spirit of Jordà (2005), applied in a panel setting. As mentioned, we first estimate what we refer to as 'reduced form' specifications. The main goal of these regressions is to verify whether in our sample, firms with different stock turnover, as measured prior to monetary policy shocks, exhibit differential responses in q, equity issuances, and investment.[16] As our baseline, we estimate panel regression specifications of the following form on our full sample of firm-level data:

$$\tilde{y}^i_{t+h} = f^i_h + d_{s,h,t+h} + \rho_h y^i_{t-1} + \beta_h x^i_{t-1} + \gamma_h x^i_{t-1} \varepsilon^m_t + u^i_{h,t+h} \tag{6}$$

$h = 0, 1, \ldots, H$ denotes the horizon at which the shock impact effects are being estimated.

y^i_t refers to firm i's outcome variable of interest, measured at the end of quarter t. Based on the notation introduced above, y^i_t is one of $\log(q^i_t)$, E^i_t/B^i_{t-1}, or I^i_t/K^i_{t-1}. In regressions estimating the responsiveness of q, $\tilde{y}^i_t = y^i_t = \log(q^i_t)$. However, regarding the other two outcome variables, we are mainly interested in the effects on firms' total equity issuance and investment in the aftermath of monetary shocks, which can play out over several quarters. Because of this, instead of studying y^i's behavior h quarters after the shock, we focus on the cumulative response of the outcome variable of interest between periods t and $t+h$. That is, whenever estimating the responsiveness of equity issuance or investment, the dependent variable $\tilde{y}^i_{t+h}$ equals $\left(\sum_{s=0}^{h} E^i_{t+s}\right)/B^i_{t-1}$, or $\left(\sum_{s=0}^{h} I^i_{t+s}\right)/K^i_{t-1}$, respectively. This can help to smooth out the lumpiness, seasonality, and noise from measurement errors in the quarterly data of equity

[16] In doing so, we are also providing a test for whether the main empirical findings of Lagos and Zhang (2020b) hold when measuring equity valuations based on q at a quarterly frequency, instead of using daily stock returns.

issuance and investment ratios, and allow for a more precise estimation of our main qualitative results. In robustness tests, we verify that that all the qualitative results hold when replacing $\tilde{y}^i_{t+h}$ with y^i_{t+h} as the dependent variable.

f^i_h denotes firm i's fixed effect in the projection at horizon h. $d_{s,h,t+h}$ is shorthand for industry-quarter dummies at the SIC 2-digit level, given the h-quarter projection horizon and the outcome variable being measured in period $t+h$. ε^m_t is a measure of the quarterly monetary policy shock as discussed above. $u^i_{h,t+h}$ is the error term in the projection of the outcome variable in period $t+h$, given the h-quarter projection horizon. $\rho_h, \beta_h, \gamma_h$ are regression coefficients. The main object of interest is the estimate for γ_h which captures any heterogeneity in shock responsiveness predicted by stock turnover.

We lag firm controls to ensure they are unaffected by the realization of ε^m_t and can be thought of as measures of shock-exposure. As long as there is persistence in stock turnover from one quarter to another, the turnover measured in $t-1$ proxies for turnover immediately before the FOMC announcement in quarter t. As discussed above, our focus is on cross-sectional differences in how firms' stock turnover predicts their responsiveness to monetary policy shocks. Including a detailed industry-time dummy $d_{s,h,t+h}$ allows for a flexible way to isolate this cross-sectional variation. Thus, the identification of the mechanism of interest is driven by *within-industry between-firm* variation across time.

Also, in order to improve the efficiency of our estimates of impulse responses, we follow the suggestion in Jordà (2005) and recursively include the residuals of the stage $h-1$ local projection as regressors in the stage h local projection. That is, whenever $h \geq 1$, specification (6) also includes $\hat{u}^i_{h-1,t+h-1}$ as a control on the right hand side. By construction, $\hat{u}^i_{h-1,t+h-1}$ is orthogonal to the regressors and reduces unexplained variation in $\tilde{y}^i_{t+h}$, thanks to persistence.[17]

We multiply all the y^i_t considered by 100 for convenience, so the coefficients for changes in q can be interpreted in percentage terms and the issuance and investment ratios in percentage points. We standardize the turnover measure x^i_t by the standard deviation of turnover in the cross-section of firms, averaged across time over our sample.[18] And we standardize the monetary shock measures ε^m_t by their standard deviation between 1990Q1–2016Q4 of approximately 9.66 bp, as measured by changes in federal funds futures rates.

Figure 1 presents the point estimates and 95% confidence intervals for γ_h given the three

[17] We verify in robustness tests that our main results survive when not using this procedure.

[18] And we retain this standardization throughout, including when splitting firms into groups.

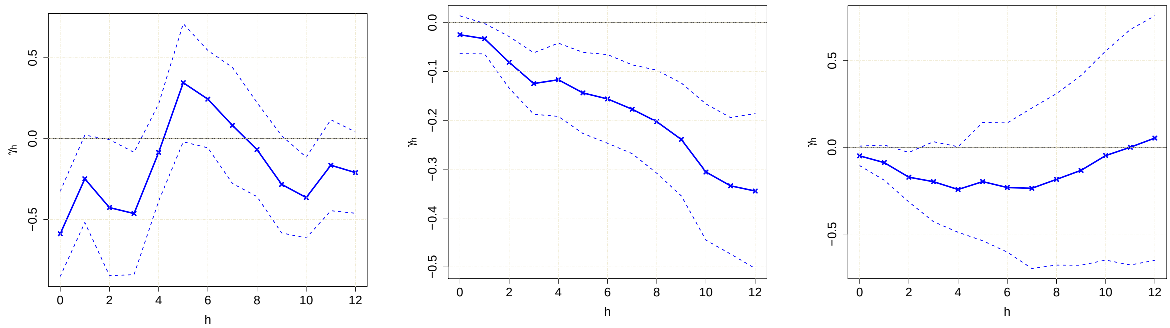
outcome variables of interest. As one would expect based on financial markets incorporating the FOMC announcements virtually immediately, the heterogeneity in stock price responses predicted by turnover is strongest in the quarter of the monetary policy shock. The point estimate of approximately -0.5 says that an increase in stock turnover by 1 sd predicts a 0.5% stronger contraction in the firm's q in the quarter of a 1 sd contractionary monetary policy shock.[19] And the predicted differences between stock prices persist for about up to a year after the shock.

Heterogeneity in the responsiveness of cumulated equity issuances predicted by stock turnover appears a quarter after the shock. Because of a persistent negative effect on quarterly issuances, the differences in net equity issuances cumulate during the three years after the shock. A 1 sd increase in stock turnover predicts an approximately 0.3 pp larger drop in net equity issuances relative to book assets during the three years after a 1 sd contractionary monetary policy shock. Finally, the last panel of Figure 1 provides evidence that higher stock turnover predicts relatively lower investment rates in the cross-section of firms after a monetary contraction. Yet the effect is just marginally statistically significant in the full sample of firm-quarters, implying that a 1 sd higher stock turnover predicts an approximately 0.2 pp larger drop in investment relative to the capital stock during the year after a 1 sd contractionary monetary shock.

Figure 6 in Appendix B.2.1 illustrates that the same qualitative predictions regarding the heterogeneous responsiveness of equity issuances and investment follow when considering the respective quarterly rates, and not their cumulation. Although, the statistical significance of the coefficient estimates is weaker, likely owing to more noise and lumpiness in these quarter-per-quarter measures. Moreover, it is evident that thanks to the persistent effects on quarterly issuance and investment rates, the cumulation of responses reveals significant total effects of monetary shocks.

The model presented above provides a stark prediction about which firms' choices should be affected by the turnover-liquidity transmission mechanism. Firms which have few liquid resources available, relative to their size, are more likely to rely on external equity financing and expose themselves to fluctuations in stock prices. Firms that do not issue equity are isolated from fluctuations in stock prices. So even though among such firms stock prices respond to monetary policy shocks, and more so for those with high turnover, their choices of equity issuance and investment are unaffected by this. And therefore, no heterogeneous responses of

[19] More precisely, given specification (6), a negative γ_h only allows to infer a drop in q *relative* to other firms.



(a) $\tilde{y}^i_{t+h} = \log(q^i_{t+h})$ (b) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} E^i_{t+s}\right)/B^i_{t-1}$ (c) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} I^i_{t+s}\right)/K^i_{t-1}$

Notes: Point estimates and 95% confidence intervals for γ_h from estimating specification (6), controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 1: Heterogeneity in responses to monetary policy shock conditional on stock turnover

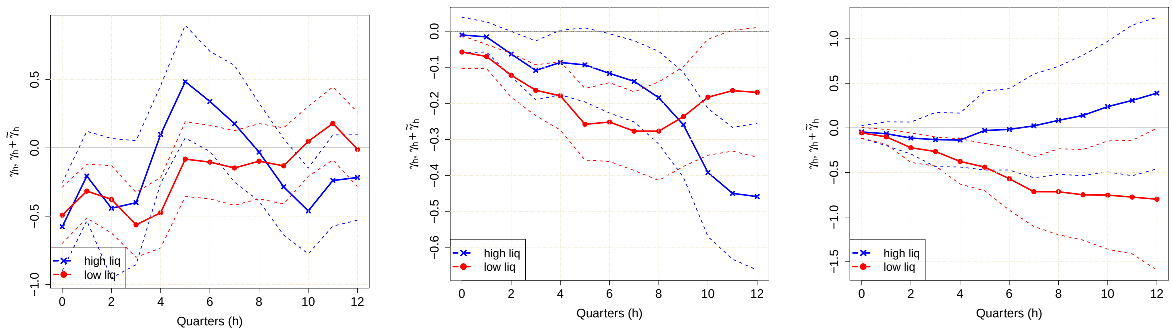
issuances and investment conditional on turnover should be observed.

To test the empirical validity of these predictions and allow for differences in the strength of the turnover-liquidity channel across groups of firms, we define the indicator $\mathbb{I}^i_{L,t}$ which equals 1 if firm i belongs in the bottom half of the liquidity ratio distribution of the cross-section of firms in quarter t, and 0 otherwise. We define the *liquidity ratio* for firm i in quarter t as the ratio of Compustat reported *cash and short-term investments* to i's total assets in t, meant to capture the holdings of various assets that firms use to manage their liquidity and financial savings. And we estimate the following specification:

$$\begin{aligned}\tilde{y}^i_{t+h} =& f^i_h + d_{s,h,t+h} + \alpha_h \mathbb{I}^i_{L,t-1} + \left(\rho_h + \tilde{\rho}_h \mathbb{I}^i_{L,t-1}\right) y^i_{t-1} \\ &+ \left(\beta_h + \tilde{\beta}_h \mathbb{I}^i_{L,t-1}\right) x^i_{t-1} + \left(\gamma_h + \tilde{\gamma}_h \mathbb{I}^i_{L,t-1}\right) x_{i,t-1}\varepsilon^m_t + u^i_{h,t+h}\end{aligned} \tag{7}$$

In this case, γ_h measures the predictive power of turnover heterogeneity for firms with high liquidity ratios prior to the shock, and $\gamma_h + \tilde{\gamma}_h$ for those with low liquidity ratios. Figure 2 presents the point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from the estimation of (7) for the three outcome variables of interest. We again include $\hat{u}^i_{h-1,t+h-1}$ as a control in (7) whenever $h \geq 1$.

The first panel in Figure 2 indicates that the predictive power of turnover heterogeneity for stock price responses is similar across the two liquidity ratio groups. As predicted by the model, the turnover-liquidity channel is operative for all stocks, with the high-turnover ones responding relatively more in the quarter of a monetary shock, independently of the firms' liquid asset positions. The point estimates for γ_0 are close to the estimates of the full sample of firms in specification (6). While the differences in stock prices persist for about a year after the shock, the statistical significance of the estimates for the high liquidity group in quarters after the shock is weakened slightly.



(a) $\tilde{y}^i_{t+h} = \log(q^i_{t+h})$ (b) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} E^i_{t+s}\right) / B^i_{t-1}$ (c) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} I^i_{t+s}\right) / K^i_{t-1}$

Notes: Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from estimating specification (7), controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 2: Heterogeneity in responses to monetary policy shock conditional on stock turnover, across liquidity ratio groups

The middle panel of Figure 2 shows that the relation between turnover and equity issuance responses to monetary policy shocks during the first two years is mainly driven by firms with low liquid asset holdings. Among such firms, an increase of 1 sd in turnover predicts an almost 0.3 pp larger cumulated decrease in equity issuances, measured as a fraction of total assets, during the two years after a 1 sd contractionary monetary shock. Also among firms with high liquidity ratios, higher turnover predicts lower equity issuances in the aftermath of policy rate increases, although this relation is weaker over the two-year horizon, and becomes more pronounced at longer horizons. The extended version of our model with long-lived firms below provides a rationale for why firms with high liquidity ratios at the time of the shock may respond with a considerable delay. This happens whenever they draw down their liquid assets and engage in equity financing while the effects of the shock on stock prices have not yet dissipated.

Finally, the estimates in the last panel of Figure 2 indicate that among firms with below median liquid asset holdings, those with higher turnover exhibit relatively lower investment rates after a contractionary monetary policy shock. For these firms, a 1 sd higher stock turnover predicts approximately 0.7 pp lower cumulated investment, relative to the capital stock, during the two years after a 1 sd contractionary monetary policy shock. As for equity issuances, the differences in investment rate responses predicted by turnover are persistent. Yet among firms with high liquidity ratios, heterogeneity in stock turnover does not predict any differential responses in investment to a monetary policy shock.

Figure 7 in Appendix B.2.1 again shows that the main findings also hold when considering the responses of quarterly rates of equity issuance and investment, without cumulating. Among firms with low liquid asset holdings, higher stock turnover predicts statistically significantly lower equity issuance rates in the impact quarter and two quarters after a contractionary shock. Significant differences in investment rate responses appear both two quarters, but also four to six quarters after a monetary shock. However, among firms with high liquidity ratios, heterogeneity in stock turnover does not predict statistically significant differences in the responses of quarterly equity issuance or investment rates.

5.4. IV regressions

We now turn to our main exercise of interest. We combine the cross-sectional heterogeneity in the monetary shock responses of Tobin's q, equity issuances and investment explained by stock turnover into an instrumental variables specification, in order to evaluate the effects of stock price fluctuations on equity issuances and investment. To do so, we construct the analogue of specification (6) by replacing the interaction term between turnover and the monetary shock $x^i\varepsilon^m$ with the firm's measure of q, which is then instrumented with the $x^i\varepsilon^m$-term.

As suggested by the OLS estimates for the reduced form specification, the heterogeneity in the monetary shock responses of q, equity issuances, and investment as explained by turnover heterogeneity can materialize at different horizons. Because of this, we consider allowing for the possibility that the variation in q instrumented by turnover and the monetary shock in period t is measured in period $t + h_q$, and the predicted effects on issuances and investment measured in period $t + h$, with $0 \leq h_q \leq h$. For example, if the effect of a monetary shock on stock prices required 1 quarter to fully materialize, yet the effects of stock price fluctuations on investment take 3 quarters to transmit, the main interest would be to study how heterogeneous variation in q in period $t + 1$ explains investment in $t + 4$ after a monetary policy shock in t. However, given that the heterogeneity in stock prices appears strongest in the impact quarter, as seen in

Figures 1a and 2a, we focus the main estimations below on the case of $h_q = 0$.

Our baseline instrumental variable specification is as follows:

$$\tilde{y}^i_{t+h} = f^i_h + d_{s,h,t+h} + \rho_h y^i_{t-1} + \beta_h x^i_{t-1} + \gamma_{h,h_q} \log\left(q^i_{t+h_q}\right) + u^i_{h,t+h} \tag{8}$$

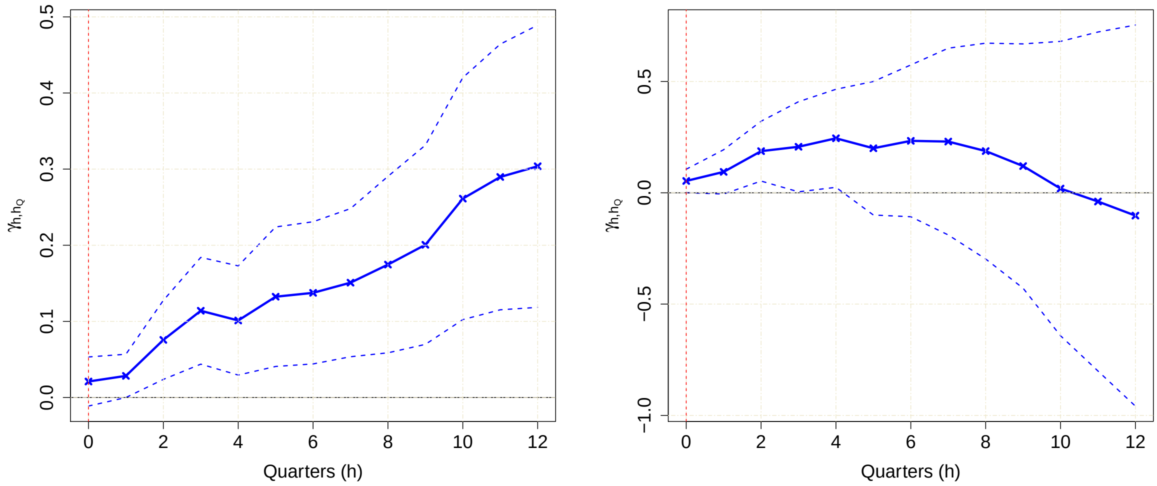
where $\log\left(q^i_{t+h_q}\right)$ is instrumented with $x_{i,t-1}\varepsilon^m_t$, and $0 \leq h_q \leq h$ for some h_q, with $h = 0, 1, \ldots, H$. Again, we also include $\hat{u}^i_{h-1,t+h-1}$ as a control in (8) whenever $h \geq 1$.

Figure 3 depicts the point estimates and 95% confidence intervals for γ_{h,h_q} from the estimation of (8) with 2SLS, given $h_q = 0$, for equity issuances and investment as dependent variables. The IV estimates are in line with what one would expect based on the reduced form OLS results in Section 5.3. The cross-sectional variation in q instrumented with turnover-based monetary shock exposure predicts higher equity issuances after increases in q caused by monetary shocks. Or, in light of the identification assumption stated in Section 5.2, this suggests that firms' equity issuances respond positively to exogenous increases in Tobin's q. The point estimates indicate that a 1% increase in q leads to a 0.3 pp increase in total equity issuances, as a fraction of total assets, during the following three years.

As suggested by the reduced form estimates, cross-sectional variation in q instrumented with monetary shocks and stock turnover also predicts slightly higher investment after increases in q caused by monetary shocks. Or, again following the identification assumptions discussed above, the estimates suggest that exogenous increases in Tobin's q lead firms to invest more. A 1% increase in q implies an approximately 0.2 pp increase in total investment, relative to the capital stock, during the following year.

Figure 8 in Appendix B.2.2 reveals that for non-cumulated response variables, the instrumented variation in q does not imply statistically significant heterogeneity in quarterly equity issuance or investment rates for the full sample of firm-quarters. However, the point estimates agree with the findings above, suggesting that exogenous increases in q tend to lead to higher equity issuances and investment.

Following the predictions of our model and the evidence presented in Section 5.3, we finally turn to estimating the IV specification by allowing for differences in coefficient estimates for firms with high versus low liquid asset holdings. Employing the indicator $\mathbb{I}^i_{L,t}$ of having a



(a) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} E^i_{t+s}\right)/B^i_{t-1}$ (b) $\tilde{y}_{i,t+h} = \left(\sum_{s=0}^{h} I^i_{t+s}\right)/K^i_{t-1}$

Notes: Point estimates and 95% confidence intervals for γ_{h,h_q} from estimating specification (8), controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Vertical red dashed line marks the value of $h_q = 0$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 3: Issuances and investment predicted by instrumented q

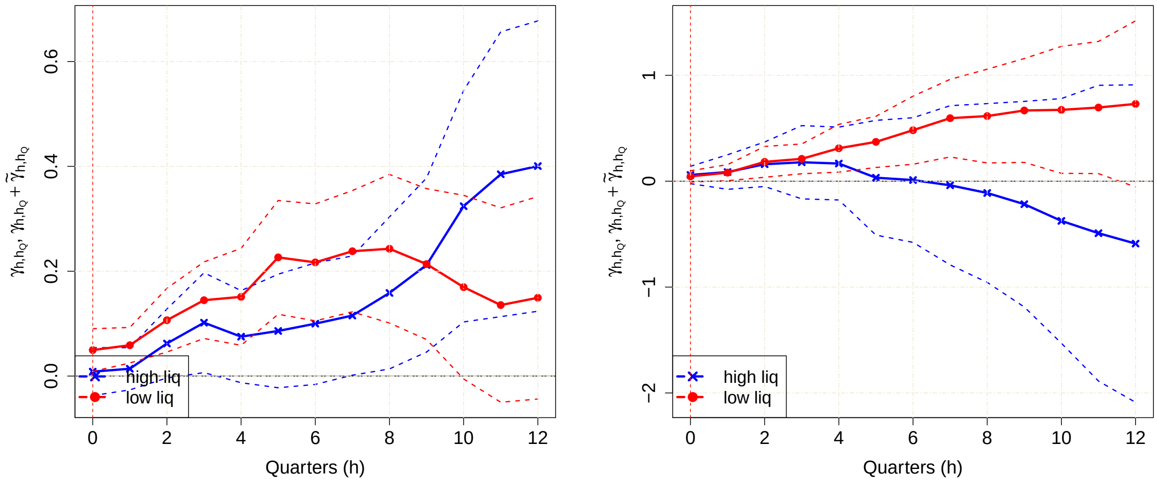
below-median liquidity ratio in t, defined in Section 5.3, we consider the following specification:

$$\begin{aligned}\tilde{y}^i_{t+h} =& f^i_h + d_{s,h,t+h} + \alpha_h \mathbb{I}^i_{L,t-1} + \left(\rho_h + \tilde{\rho}_h \mathbb{I}^i_{L,t-1}\right) y^i_{t-1} \\ &+ \left(\beta_h + \tilde{\beta}_h \mathbb{I}^i_{L,t-1}\right) x^i_{t-1} + \left(\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q} \mathbb{I}^i_{L,t-1}\right) \log\left(q^i_{t+h_q}\right) + u^i_{h,t+h} \qquad (9)\end{aligned}$$

where the vector $\left[\log\left(q^i_{t+h_q}\right), \mathbb{I}^i_{L,t-1} \log\left(q^i_{t+h_q}\right)\right]$ is instrumented with $\left[x^i_{t-1}\varepsilon^m_t, \mathbb{I}^i_{L,t-1} x^i_{t-1}\varepsilon^m_t\right]$. As in all the specifications so far, we also include $\hat{u}^i_{h-1,t+h-1}$ as a control in (9) whenever $h \geq 1$.

Figure 4 presents the point estimates and 95% confidence intervals for γ_{h,h_q} and $\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q}$ from the estimation of (9) given $h_q = 0$, for equity issuances and investment as dependent variables. Again, the IV estimates confirm the findings of the reduced form regressions. Among firms with low liquid asset holdings, the cross-sectional variation in q instrumented with turnover and identified monetary policy shocks, predicts significant heterogeneity in equity issuances. A 1% increase in q leads to a more than 0.2 pp increase in total equity issuances during the next two years, as measured relative to balance sheet size. For firms with high liquidity ratios, the positive relation between instrumented variation in q and equity issuances is weaker at the two year horizon, but becomes more evident later on.

Finally, increases in instrumented q predict higher investment for firms with low liquid asset holdings. For these firms, a 1% increase in q implies an approximately 0.7 pp higher cumulated investment relative to capital over the three years thereafter. For firms with liquidity ratios above the median, instrumented variation in q does not predict heterogeneity in investment.



(a) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} E^i_{t+s}\right) / B^i_{t-1}$ (b) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} I^i_{t+s}\right) / K^i_{t-1}$

Notes: Point estimates and 95% confidence intervals for γ_{h,h_q} and $\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q}$ from estimating specification (9), controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Vertical red dashed line marks the value of $h_q = 0$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 4: Issuances and investment predicted by instrumented q, across liquidity ratio groups

Again, Figure 9 in Appendix B.2.2 illustrates that the main findings hold also for the responses of quarterly rates of equity issuance and investment. For low-liquidity firms, increases in q, as instrumented by monetary shocks and stock turnover, imply significantly higher equity issuances in the same quarter and two quarters later. Significantly higher investment rates follow both two quarters and four to six after the initial increase in q.

Robustness. In Appendix B.3, Figure 10 we include additional firm-level controls alongside x^i_{t-1} in specification (9) to verify that the predicted heterogeneity in issuance and investment responsiveness is not in fact explained by other firm-level covariates. As discussed in Section 5.2, we consider as the main concerns measures of size, leverage and liquidity ratios. In addition, we add firm age as a control. Comparing the results in Figures 4 and 10, it is clear that while the confidence intervals on the estimates of γ_{h,h_q} and $\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q}$ widen due to cross-sectional correlation between stock turnover and the various firm-level controls, the point estimates are in large part unchanged and our main results hold. An increase in firms' q, as instrumented by stock turnover and monetary policy shocks, leads to higher equity issuance and investment among low-liquidity firms, and this finding cannot be explained by the other firm-level covariates being correlated with turnover and predicting heterogeneous responsiveness to monetary shocks. Figure 11 in Appendix B.3 illustrates that our main findings hold when dropping the $h-1$ horizon residuals $\hat{u}^i_{h,t+h-1}$ as regressors in the local projection at horizon h.

Also, in Figures 12 and 13 in Appendix B.3, we present OLS and IV coefficient estimates for alternative ε^m_t series: the Jarociński and Karadi (2019) VAR-implied shock series and their 'poor man's sign restrictions' series. When considering the VAR-implied shock series, we drop data after 2007Q4. Fitting a linear VAR on aggregate time series during the financial crisis and especially the zero lower bound period with nonlinear dynamics can potenially amplify imprecisions in the inference of monetary shock series. As seen from the figures, our main findings hold when potential informational effects of policy announcements are purged from the monetary shock series.

6. Quantitative analysis

In this section we use a quantitative version of the model presented in Section 2 to assess the ability of the theory to match the dynamic responses of equity issuance and investment documented in Section 5. The theory consists of two building blocks: an asset-pricing block that determines equity prices given monetary policy, and an investment block that determines the capital structure and investment decisions of firms.

We extend the theory of Section 2 and introduce monetary policy shocks in the form of an unexpected change in the path of the effective nominal interest rate on illiquid bonds between any two consecutive second subperiods.[20] In the notation introduced earlier, the (gross) rate of inflation between the second subperiod of t and the second subperiod of $t+1$ is $\frac{\phi_t}{\phi_{t+1}}$. And the (gross) real interest rate of the one-period real pure-discount bond in the corresponding periods is the inverse of its real price in t, priced by the investors: $\left(\phi^b_t\right)^{-1} = \beta^{-1}$. Therefore, the implied net nominal interest rate on an illiquid bond between t and $t+1$ is: $r^n_{t+1} \equiv \frac{\phi_t}{\beta\phi_{t+1}} - 1$, relating

[20]Although the model was set up with money injections being the instrument of monetary policy, there always exists an announced path of money growth $\frac{M_{t+1}}{M_t}$ consistent with a given path of equilibrium nominal interest rates.

the nominal rate to the model equilibrium outcomes presented earlier.

The shock we consider is an unexpected increase of ε^m in r^n_{t+1} in period $t = 0$, after which the nominal rate follows an autoregressive path back to its steady state value according to: $r^n_{t+1} = \bar{r}^n + \rho_n (r^n_t - \bar{r}^n)$ where $\bar{r}^n$ is the steady state net nominal rate. We choose ε^m so as to generate a 1% increase in firms' stock prices at the time of the announcement of the shock, conditional on the other parameter values.

For simplicity we currently consider an economy without heterogeneity nor uncertainty or growth in entrepreneurs' productivity, so $A^i_t = A$, $\forall(i,t)$ for some parameter $A \in \mathbb{R}_{++}$. However, we extend the entrepreneur's problem from Section 2 by introducing stochastic fixed equity issuance costs. More specifically, we assume that for an entrepreneur with capital stock K^i_t to issue new equity in period t, i.e. choose $E^i_t > 0$ in the second subperiod of t, he must excert effort and suffer a disutility of $\xi^i_t K^i_t$. The stochastic cost ξ^i_t is i.i.d. across entrepreneurs and time, distributed uniformly $\xi^i_t \sim U\left[0, \bar{\xi}\right], \forall(i,t)$, and is drawn at the beginning of the second subperiod of t by each entrepreneur. As illustrated by the analytical example in Section 4, the introduction of this equity issuance cost is in no way necessary to produce our main qualitative results. Rather, its main purpose is to, in a straighforward manner, improve the quantitative characteristics and flexibility of the model, most importantly in yielding a more realistic fraction of firms issuing equity at any given point in time, and a nontrivial stationary distribution of liquid asset holdings.

As for the remaining functional forms in the model, we assume quadratic capital adjustment costs $\Phi(I_t/K_t) = \frac{\eta}{2}\left(\frac{I_t}{K_t}\right)^2$, and a lognormal distribution G for $\varepsilon \sim \log\mathcal{N}(\mu_\varepsilon, \sigma_\varepsilon)$. For the entrepreneur's problem, the relevant idiosyncratic state variable is the ratio of bond holdings to its capital stock.[21] For the exercises relevant below, the characteristics of entrepreneurs being born simply need to be specified in terms of the distribution of this ratio. Because *ex post* heterogeneity of entrepreneurs is generated by the stochastic debt issuance costs and the occurrence of death, we simply assume that all entrepreneurs are born with a given bonds to capital, or *liquidity*, ratio $\omega_0 \in \mathbb{R}_{++}$.

As the main exercise, we compare the impulse responses of cumulated investment for firms with high and low liquidity ratios in the stationary distribution of our model to the estimates from the data. The empirical IV coefficients from Section 5.4 estimate how much investment

[21] The entrepreneur's problem is homogeneous of degree 1 in K^i_t. So choices of investment rates, equity issuance rates, and bond holdings relative to capital are independent of the incoming capital stock.

rates respond to a 1% increase in q generated by a monetary policy shock. In the stylized model of Section 2, the *only* channel of monetary transmission from nominal rates to stock prices and investment is the turnover-liquidity channel. Therefore, we can simply study the impulse responses of *ex ante* identical firms (who also have identical stock turnover), with *ex post* heterogeneous liquidity positions. Whereas in the data, it was necessary to employ cross-sectional variation in the monetary shock responses of firms with different stock turnover to identify and isolate the turnover-liquidity channel.

The parameter values we currently use for the quantitative exercise are chosen based on one time period being a quarter: $\beta = 0.995$, $\delta = 0.025$, $1 - \pi = 0.017$ (exit rate targeted by Begenau and Salomao (2019)), $\alpha = \theta = 1$, $\rho_n = 0.5$, $\bar{r}^n = 0.04/4$. as Lagos and Zhang (2020b), we consider a baseline calibration $\theta = 1$ to abstract from micro-level pricing frictions induced by bargaining. Also, given that the current quantitative exercise does not rely on turnover heterogeneity among firms in the model, we consider a baseline $\alpha = 1$. We calibrate σ_ε in the distribution of ε so that the stock price sensitivity of the firms (with $\alpha = 1$) in the model matches the impact effects of monetary policy shocks on the prices of the 10% highest turnover stocks in our empirical work.[22] And we normalize $\mu_\varepsilon = -\frac{\sigma_\varepsilon^2}{2}$. We use $\omega_0 = 0.4$ which is the approximate average cash-to-assets ratio of firms "entering" Compustat, i.e. engaging in an IPO and entering our sample of public firms, during the period that we study, following Begenau and Palazzo (2020).

We calibrate the values of the remaining parameters ε_E, A, $\bar{\xi}$, and η to match moments yielded by the stationary equilibrium of our model to the sample of Compustat firms used in our empirical analysis of Section 5. More specifically, we target: the median liquidity ratio (8.0%), the median investment rate among low-liquidity (below median) firms (4.0%), the unconditional frequency of equity issuance[23] among all firms in our sample (0.26), and the average after-depreciation profitability of capital (8.2%). Regarding the latter, we use the entrepreneurs' utility ε_E as the relative price of dividends paid in good 1, relative to good 2, and calculate the profitability of a unit of capital after depreciation in the model as $\varepsilon_E A - \delta$.

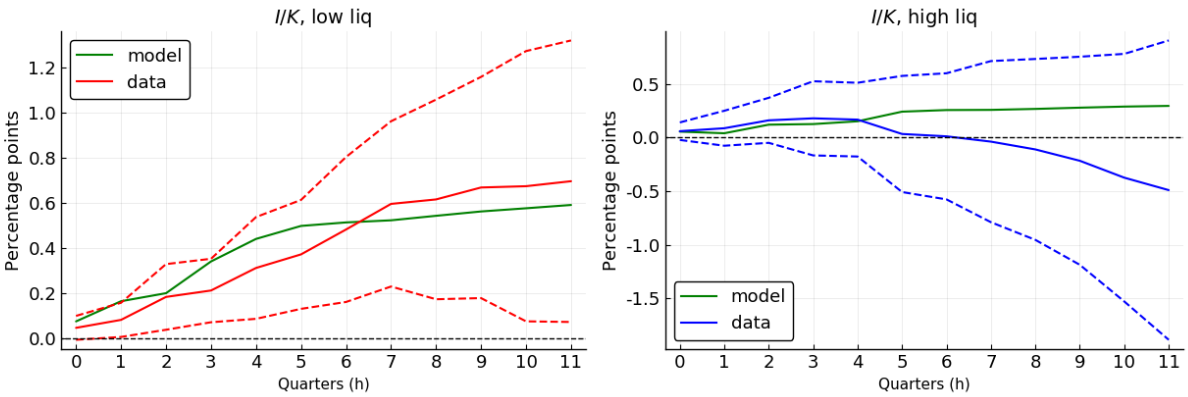
Figure 5 depicts the model impulse responses alongside the corresponding point estimates and confidence intervals already presented in panel (b) of Figure 4 in Section 5.4. For low-

[22] Given that in this simple model, the only real effect of nominal rate shocks works through their effect on firms' stock prices and we normalize the monetary shock size in our main exercise so that stock prices respond by 1%, this choice simply governs the size of the required nominal rate shock in the background.

[23] We define the incidence of a firm issuing equity in our sample as the net equity issuance to asset ratio E_t^i/B_{t-1}^i being above 0.1% in a given quarter.

liquidity firms, investment rates in the model respond slightly faster than in the data. But the overall, cumulated effect on investment is very similar across the two.

For high-liquidity firms, the average responses in the model as in the data are smaller, although not zero. This happens because of two main reasons. First, in any given period, some firms designated as "high-liquidity" may get low enough draws of the equity issuance cost ξ_t^i and take advantage of the beneficial circumstances of issuing equity. Although, they are significantly less likely to issue equity than the low-liquidity firms. But if they happen to do so exactly at the time of the monetary shock, their investment will respond to the change in the price of equity and is thus not "isolated" from the shock. Second, whenever not issuing equity, high-liquidity firms draw down their liquid assets, slowly becoming "low-liquidity", and experience an increase in their probability of issuing equity over time. If the monetary shock is persistent and its effects on stock prices last for several periods, their direct effects on these firms simply appear with a lag, and to a smaller extent, depending on the shock persistence. Moreover, because the high-liquidity firms anticipate this immediately when the shock is revealed, and they want to smooth investment due to the convex adjustment costs, they may respond already at shock impact. To do so, they invest more out of their liquid asset holdings, even though they are not yet accessing the equity market.



(a) Low liquidity ratio firms (b) High liquidity ratio firms

Notes: Data refers to point estimates and 95% confidence intervals for γ_{h,h_q} and $\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q}$ from estimating specification (9) with $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} I^i_{t+s}\right) / K^i_{t-1}$ as the outcome variable. *Model* response is computed as the impulse response of the exact same cumulated response of investment relative to pre-shock capital stock, averaged over a large panel of firms drawn from the stationary distribution of the model. High and low liquidity ratios are defined as above or below the cross-sectional median liquidity ratio.

Figure 5: Comparison of cumulative investment rate responses from model and data estimates

7. Aggregate relevance in monetary transmission

Having established that our empirical estimates of the q-monetary, or turnover, channel are both qualitatively and quantitatively consistent with the calibrated theoretical model, we proceed to provide a back-of-the-envelope (partial equilibrium) assessment of the importance of the channel for monetary transmission to aggregate investment. We do so by directly employing our empirical regression estimates from Section 5, instead of relying on the structural model.

We first provide a brief discussion on how our empirical estimates based on between-firm variation can allow us to take the extra step and give an assessment of the overall effect of monetary transmission working through the turnover channel. To fix notation, let us use $\frac{dy}{dx}\Big|^{\text{TC}}$ to denote the effect of variable x on y *through the turnover channel*. This is in contrast to $\frac{dy}{dx}$ by which we mean the effect of x on y *through all possible transmission channels*. For concreteness, let us first focus the discussion on the effects that monetary policy shocks have on q through the turnover channel. The estimates of γ_h from the reduced form OLS regressions of Section 5.3 provide an estimate of $\frac{d^2 \log\left(q^i_{t+h}\right)}{d\varepsilon^m_t dx^i_{t-1}}$. That is, $\widehat{\gamma}_h$ captures how the estimated effect of ε^m_t on $\log\left(q^i_{t+h}\right)$ differs conditional on past turnover x^i_{t-1}. By the identifying assumption that differences in firms' responses, as predicted by turnover, appear *only* because of the turnover channel, we can attribute these differences in full to the turnover channel, i.e. $\frac{d^2 \log\left(q^i_{t+h}\right)}{d\varepsilon^m_t dx^i_{t-1}} = \frac{d^2 \log\left(q^i_{t+h}\right)}{d\varepsilon^m_t dx^i_{t-1}}\Big|^{\text{TC}}$, estimated by γ_h.

However, without further moment restrictions or identifying assumptions, regressions relying on between-firm differences in responses only allow to identify these cross-derivatives: they tell us how the monetary shock affects the q of firms with different turnover differently (through the turnover channel). Yet the ultimate goal is to evaluate how the monetary shock affects firms' q through the turnover channel. That is, we would like to identify the first derivative $\frac{d \log\left(q^i_{t+h}\right)}{d\varepsilon^m_t}\Big|^{\text{TC}}$. Continuing with imposing linearity, one could "integrate out" x^i_{t-1} from the cross-derivatives and write:

$$\frac{d \log\left(q^i_{t+h}\right)}{d\varepsilon^m_t}\Big|^{\text{TC}} = \bar{\gamma}^i_h + \gamma_h x^i_{t-1}$$

where $\bar{\gamma}^i_h$ could be thought of as a "missing intercept" (Wolf, 2019) – the (potentially firm specific) effect of monetary shocks on q^i_{t+h} through the turnover channel that is not explained by variation in turnover. $\bar{\gamma}^i_h$ cannot be identified solely based on our empirical regressions. But it can be identified based on our theoretical model of the turnover channel. For all stocks with zero turnover, the turnover channel is inactive. So the effect of monetary shocks on the corresponding firms through the channel must be zero. And we can pin down the missing empirical "intercept" as:

$$\frac{d\log\left(q^i_{t+h}\right)}{d\varepsilon^m_t}\Bigg|^{\text{TC}}_{x^i_{t-1}=0} = 0 \Longrightarrow \bar{\gamma}^i_h = 0 \;\text{ and }\; \frac{d\log\left(q^i_{t+h}\right)}{d\varepsilon^m_t}\Bigg|^{\text{TC}} = \gamma_h x^i_{t-1}$$

Note, importantly, that due to the stylized nature of our theoretical model, there exist no general equilibrium effects through which responsive firms can affect market prices, which in turn influence firms with zero stock turnover. So based on our model, this additional moment restriction is precise. In reality, its validity depends on whether such general equilibrium feedback effects are negligible or not.

Having established that $\frac{d\log\left(q^i_{t+h}\right)}{d\varepsilon^m_t}\Big|^{\text{TC}}$ can be gauged using $\widehat{\gamma}_h x^i_{t-1}$, we compute that in our Compustat sample, across time and firms, the average effect of a 25 bp contractionary shock in ε^m_t, as measured by quarterly aggregated 3m Federal funds futures rate changes, is to decrease q^i_t by 1.61% at impact through the turnover channel.

Next, we can use the IV estimates from Section 5.4 to evaluate the effects of monetary shocks through the turnover channel on firms' investment. Based on our identification assumptions, the IV coefficient $\gamma_{h,0}$ in specification (8) for $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^h I^i_{t+s}\right)/K^i_{t-1}$ provides an estimate of $\frac{d\left(\sum_{s=0}^h I^i_{t+s}\right)/K^i_{t-1}}{d\log\left(q^i_t\right)}\Big|^{\text{TC}}$. By the chain rule, let us therefore write:

$$\frac{d\left(\sum_{s=0}^h I^i_{t+s}\right)/K^i_{t-1}}{d\varepsilon^m_t}\Bigg|^{\text{TC}} = \frac{d\left(\sum_{s=0}^h I^i_{t+s}\right)/K^i_{t-1}}{d\log\left(q^i_t\right)}\Bigg|^{\text{TC}} \times \frac{d\log\left(q^i_t\right)}{d\varepsilon^m_t}\Bigg|^{\text{TC}} = \gamma_{h,0} \times \gamma_0 x^i_{t-1}$$

where $\gamma_{h,0}$ refers to the coefficient on the instrumented $\log\left(q^i_{t+h_q}\right)$ in specification (8) for $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^h I^i_{t+s}\right)/K^i_{t-1}$, with $h_q = 0$. And γ_0 refers to the coefficient on $x^i_{t-1}\varepsilon^m_t$ in specification (6) for $\tilde{y}^i_t = \log\left(q^i_t\right)$. Based on this, we compute that in our Compustat sample, across time and firms, the average effect of a 25 bp contractionary shock in ε^m_t is to decrease $\left(\sum_{s=0}^4 I^i_{t+s}\right)/K^i_{t-1}$, i.e. the relative cumulated investment in the shock quarter and the year after that, by 0.39 pp through the turnover channel.

Finally, to assess the relevance of the turnover channel in monetary transmission to aggregate investment, we compute the implied semi-elasticity of firm i's quarterly investment with respect to ε^m_t based on the estimates of $\frac{d\left(\sum_{s=0}^4 I^i_{t+s}\right)/K^i_{t-1}}{d\varepsilon^m_t}\Big|^{\text{TC}}$ relative to I^i_{t-1}/K^i_{t-2}. For each quarter t, we compute the cross-sectional average of these semi-elasticities, weighted by firms' capital expenditures I^i_{t-1}, in our Compustat panel, to get an estimate of the semi-elasticity of aggregate public firm investment in quarter t. Taking the average of these aggregate semi-elasticities across time and adjusting for the share of approximately 46.5% of US aggregate nonresidential investment being done by public firms (Asker et al., 2011), we find that in response to a 25 bp unexpected increase in the Federal funds rate, quarterly aggregate investment drops by 0.25% due to the q-monetary channel. For comparison, the corresponding peak effect on aggregate investment estimated by Christiano et al. (2005) is approximately 0.45%. We can thus conclude that the effects of monetary policy shocks on public firms' investment due to equity price responses have the potential to explain a nonnegligible fraction of overall monetary transmission to aggregate investment in the US.

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A. Appendix: proofs

Proof of Proposition 1. The Lagrangian for the optimization problem of the one-period-lived entrepreneur at entry, i.e., (5), is

$$\begin{aligned}\mathcal{L} &= c_t + \beta\varepsilon_E A^i\left[(1-\delta)\underline{K}_t^i + I_t - S_{t+1}^i\right] \\ &\quad +\xi\left[\psi_t^i S_{t+1}^i + w_t^i - c_t - C\left(I_t, \underline{K}_t^i\right)\right] \\ &\quad +\xi_c^+ c_t + \xi_S^+ S_{t+1}^i + \xi_K^+\left[(1-\delta)\underline{K}_t^i + I_t\right] \\ &\quad +\xi_S^-[(1-\delta)\underline{K}_t^i + I_t - S_{t+1}^i].\end{aligned}$$

The first-order conditions are

$$0 = 1 - \xi + \xi_c^+ \tag{10}$$

$$0 = \beta\varepsilon_E A^i - \xi C_1(I_t/\underline{K}_t^i) + \xi_K^+ + \xi_S^- \tag{11}$$

$$0 = -\beta\varepsilon_E A^i + \xi\psi_t^i + \xi_S^+ - \xi_S^- \tag{12}$$

$$0 = \xi\left[\psi_t^i S_{t+1}^i + w_t^i - c_t - C\left(I_t, \underline{K}_t^i\right)\right] \tag{13}$$

$$0 = \xi_c^+ c_t \tag{14}$$

$$0 = \xi_S^+ S_{t+1}^i \tag{15}$$

$$0 = \xi_K^+\left[(1-\delta)\underline{K}_t^i + I_t\right] \tag{16}$$

$$0 = \xi_S^-[(1-\delta)\underline{K}_t^i + I_t - S_{t+1}^i]. \tag{17}$$

Condition (10) implies $\xi = 1 + \xi_c^+ > 0$, so (13) implies

$$0 = \psi_t^i S_{t+1}^i + w_t^i - c_t - C\left(I_t, \underline{K}_t^i\right). \tag{18}$$

There are potentially twelve cases depending on whether the multipliers ξ_c^+, ξ_S^+, ξ_S^-, and ξ_K^+ are positive or equal to zero, but given the assumptions in the proposition, at an optimum, the binding patterms must be as in one of the following five cases.

Case I: $\xi_S^+ = \xi_c^+ = \xi_K^+ = 0 < \xi_S^-$. In this case the solution is

$$\begin{aligned}\psi_t^i &= C_1(I_t/\underline{K}_t^i) \\ S_{t+1}^i &= I_t \\ c_t &= \psi_t^i I_t + w_t^i - C\left(I_t, \underline{K}_t^i\right),\end{aligned}$$

provided the following conditions hold

$$\begin{aligned} 0 &\leq \psi_t^i I_t + w_t^i - C\left(I_t, \underline{K}_t^i\right) \\ 0 &\leq I_t \\ \beta\varepsilon_E A^i &< \psi_t^i. \end{aligned}$$

Case II: $\xi_S^- = \xi_S^+ = \xi_K^+ = \xi_c^+ = 0$. In this case the solution is

$$\beta\varepsilon_E A^i = C_1(I_t/\underline{K}_t^i)$$

and any pair $\left(c_t, S_{t+1}^i\right) \in \mathbb{R}_+ \times [0, I_t]$ that satisfies

$$c_t = \psi_t^i S_{t+1}^i + w_t^i - C\left(I_t, \underline{K}_t^i\right),$$

provided the following condition holds

$$\beta\varepsilon_E A^i = \psi_t^i.$$

Case III: $\xi_S^- = \xi_K^+ = \xi_c^+ = 0 < \xi_S^+$. In this case the solution is

$$\begin{aligned} S_{t+1}^i &= 0 \\ I_t \text{ solves } C_1(I_t/\underline{K}_t^i) &= \beta\varepsilon_H A^i \\ c_t &= w_t^i - C\left(I_t, \underline{K}_t^i\right), \end{aligned}$$

provided the following conditions hold

$$\begin{aligned} 0 &\leq I_t \\ 0 &\leq w_t^i - C\left(I_t, \underline{K}_t^i\right) \\ \psi_t^i &< \beta\varepsilon_E A^i. \end{aligned}$$

Case IV: $\xi_S^- = \xi_K^+ = 0 < \min(\xi_S^+, \xi_c^+)$. In this case the solution is

$$\begin{aligned} c_t &= 0 \\ S_{t+1}^i &= 0 \\ I_t \text{ solves } C\left(I_t, \underline{K}_t^i\right) &= w_t^i, \end{aligned}$$

provided the following conditions hold

$$\psi_t^i < C_1(I_t/\underline{K}_t^i) < \beta\varepsilon_E A^i.$$

Case V: $\xi_S^- = \xi_S^+ = \xi_K^+ = 0 < \xi_c^+$. In this case the solution is

$$\begin{aligned} c_t &= 0 \\ 0 &= \psi_t^i - C_1(I_t/\underline{K}_t^i) \\ S_{t+1}^i &= \frac{C\left(I_t, \underline{K}_t^i\right) - w_t^i}{\psi_t^i}, \end{aligned}$$

provided the following conditions hold

$$\begin{aligned} \psi_t^i &< \beta\varepsilon_E A^i \\ C_1(I_t/\underline{K}_t^i) &< \beta\varepsilon_E A^i \\ 0 &\leq \frac{C\left(I_t, \underline{K}_t^i\right) - w_t^i}{\psi_t^i} \leq I_t. \end{aligned}$$

This concludes the proof. ■

Lemma 1. *The value function $W_t\left(\boldsymbol{a}_t, \varphi_t\right)$ in (2) can be written as*

$$W_t\left(\boldsymbol{a}_t, \varphi_t\right) = \phi_t m_t + \int_{i\in\mathcal{F}} \left[\bar{\psi}_t^i s_t^i + b_t^i\right] di - \varphi_t + T_t + W_t^0, \tag{19}$$

where $\boldsymbol{a}_t \equiv (m_t, [b_t^i]_{i\in\mathcal{F}}, [s_t^i]_{i\in\mathcal{F}})$, and

$$W_t^0 \equiv \max_{m_{t+1},[b_{t+1}^i, s_{t+1}^i]_{i\in\mathcal{F}}} \left[-\phi_t m_{t+1} - \int_{i\in\mathcal{F}} \left(\psi_t^i s_{t+1}^i + \frac{1}{R_t^i} b_{t+1}^i\right) di + \beta \int V_{t+1}\left(\boldsymbol{a}_{t+1}, \varepsilon\right) dG(\varepsilon)\right] \tag{20}$$

$$\text{s.t. } m_{t+1}, b_{t+1}^i, s_{t+1}^i \in \mathbb{R}_+.$$

Proof. Substitute the budget constraint and collect terms. ■

Consider a bargaining situation in the OTC round of period t between a broker and an investor who has portfolio $\boldsymbol{a}_t$ and valuation ε, and let $[\overline{\boldsymbol{a}}_t\left(\boldsymbol{a}_t, \varepsilon\right), \varphi_t\left(\boldsymbol{a}_t, \varepsilon\right)]$ denote the corresponding bargaining outcome. For what follows, it is convenient to let $\Gamma_t\left(\boldsymbol{a}_t, \varepsilon\right)$ denote the investor's gain from trade from this bilateral negotiation. That is,

$$\begin{aligned} \Gamma_t\left(\boldsymbol{a}_t, \varepsilon\right) \equiv\ & \int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} \overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right) di \\ & + W_t\left(\overline{m}_t\left(\boldsymbol{a}_t, \varepsilon\right), [b_t^i]_{i\in\mathcal{F}}, [\pi \overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right) + (1-\pi) S_t^i]_{i\in\mathcal{F}}, \varphi_t\left(\boldsymbol{a}_t, \varepsilon\right)\right) \\ & - \left[\int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} s_t^i di + W_t\left((m_t, [b_t^i]_{i\in\mathcal{F}}, [\pi s_t^i + (1-\pi) S_t^i]_{i\in\mathcal{F}}), 0\right)\right]. \end{aligned} \tag{21}$$

Lemma 2. *Consider a bargaining situation in the OTC round of period t between a broker and an investor who has portfolio $\boldsymbol{a}_t = (m_t, \boldsymbol{b}_t, \boldsymbol{s}_t)$, with $\boldsymbol{b}_t = \left[b_t^i\right]_{i\in\mathcal{F}}$ and $\boldsymbol{s}_t = \left[s_t^i\right]_{i\in\mathcal{F}}$, and valuation ε. Define*

$$\begin{aligned}
\varepsilon_t^{i*} &\equiv \frac{p_t^i \phi_t - \pi \bar{\psi}_{t+1}^i}{r_t^{K,i}} \\
\vartheta_t^i(\varepsilon) &\equiv \frac{(\varepsilon - \varepsilon_t^{i*}) r_t^{K,i}}{p_t^i} \\
\mathcal{F}_t^*(\varepsilon) &= \left\{ i \in \mathcal{F} : i \in \arg\max_{s\in\mathcal{F}} \vartheta_t^s(\varepsilon) \right\} \\
\vartheta_t^*(\varepsilon) &= \max_{s\in\mathcal{F}} \vartheta_t^s(\varepsilon).
\end{aligned}$$

Then:

(i) The investor's post-OTC-trade equity portfolio is any $\left[\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon)\right]_{i\in\mathcal{F}}$ that satisfies:

$$\begin{aligned}
0 &\leq \bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) \ \textit{for all } i \in \mathcal{F} \\
0 &= \bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) \ \textit{if } \vartheta_t^i(\varepsilon) < 0 \textit{ or } \vartheta_t^i(\varepsilon) < \vartheta_t^*(\varepsilon) \\
m_t &\geq \int_{i\in\mathcal{F}} p_t^i [\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) - s_t^i] di \ \textit{if } \vartheta_t^*(\varepsilon) \leq 0 \\
m_t &= \int_{i\in\mathcal{F}} p_t^i [\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) - s_t^i] di \ \textit{if } 0 < \vartheta_t^*(\varepsilon).
\end{aligned}$$

(ii) The investor's post-OTC-trade money holding is

$$\bar{m}_t(\boldsymbol{a}_t, \varepsilon) = m_t - \int_{i\in\mathcal{F}} p_t^i \left[\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) - s_t^i\right] di. \tag{22}$$

(iii) The negotiated fee is

$$\varphi_t(\boldsymbol{a}_t, \varepsilon) = (1-\theta) \int_{i\in\mathcal{F}} (\varepsilon - \varepsilon_t^{i*}) r_t^{K,i} \left[\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) - s_t^i\right] di. \tag{23}$$

(iv) The investor's gain from trade in the OTC round is

$$\Gamma_t(\boldsymbol{a}_t, \varepsilon) = \theta \int_{i\in\mathcal{F}} (\varepsilon - \varepsilon_t^{i*}) r_t^{K,i} \left[\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) - s_t^i\right] di. \tag{24}$$

Proof. With (19), we have

$$W_t(\tilde{\boldsymbol{a}}_t, \varphi_t) = \phi_t \bar{m}_t + \int_{i\in\mathcal{F}} \left\{ \bar{\psi}_t^i [\pi \bar{s}_t^i + (1-\pi) S_t^i] + \bar{b}_t^i \right\} di + T_t + W_t^0 - \varphi_t \tag{25}$$

$$W_t(\boldsymbol{a}_t', 0) = \phi_t m_t + \int_{i\in\mathcal{F}} \left\{ \bar{\psi}_t^i [\pi s_t^i + (1-\pi) S_t^i] + b_t^i \right\} di + T_t + W_t^0. \tag{26}$$

With (25) and (26), we can write the investor's gain from trade in a bilateral bargain, as

$$
\begin{aligned}
& \varepsilon\bar{\mathrm{Y}}_t + W_t\left(\tilde{\boldsymbol{a}}_t, \varphi_t\right) - \varepsilon \mathrm{Y}_t - W_t\left(\boldsymbol{a}_t', 0\right) \\
= \;& \int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} \overline{s}_t^i di + \left[\phi_t \overline{m}_t + \int_{i\in\mathcal{F}} \{\bar{\psi}_t^i[\pi \overline{s}_t^i + (1-\pi)\, S_t^i] + \overline{b}_t^i\} di - \varphi_t\right] \\
& - \left\{\int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} s_t^i di + \left[\phi_t m_t + \int_{i\in\mathcal{F}} \{\bar{\psi}_t^i[\pi s_t^i + (1-\pi)\, S_t^i] + b_t^i\} di\right]\right\}.
\end{aligned}
$$

Thus, the post-trade money and equity holdings that solve the bargaining problem (1) are

$$
\begin{aligned}
\left(\overline{m}_t\left(\boldsymbol{a}_t, \varepsilon\right), [\overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right)]_{i\in\mathcal{F}}\right) &= \arg\max_{\overline{m}_t, [\overline{s}_t^i]_{i\in\mathcal{F}}} \left[\int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} \overline{s}_t^i di + \phi_t \overline{m}_t \right. \\
& \quad \left. + \int_{i\in\mathcal{F}} \left\{\bar{\psi}_t^i[\pi \overline{s}_t^i + (1-\pi)\, S_t^i] + b_t^i\right\} di\right] \qquad (27)
\end{aligned}
$$

$$
\begin{aligned}
\text{s.t. } \overline{m}_t + \int_{i\in\mathcal{F}} p_t^i \overline{s}_t^i di &\leq m_t + \int_{i\in\mathcal{F}} p_t^i s_t^i di \qquad (28) \\
\overline{m}_t, \overline{s}_t^i &\in \mathbb{R}_+ \text{ for all } i \in \mathcal{F}, \qquad (29)
\end{aligned}
$$

and the negotiated fee is given by

$$
\begin{aligned}
\varphi_t\left(\boldsymbol{a}_t, \varepsilon\right) &= (1-\theta)\left\{\int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} \overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right) di - \int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} s_t^i di \right. \\
& \quad + \left(\phi_t \overline{m}_t\left(\boldsymbol{a}_t, \varepsilon\right) + \int_{i\in\mathcal{F}} \left\{\bar{\psi}_t^i[\pi \overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right) + (1-\pi)\, S_t^i] + b_t^i\right\} di\right) \\
& \quad \left. - \left(\phi_t m_t + \int_{i\in\mathcal{F}} \{\bar{\psi}_t^i[\pi s_t^i + (1-\pi)\, S_t^i] + b_t^i\} di\right)\right\}. \qquad (30)
\end{aligned}
$$

From (27)-(29), we conclude that

$$
\overline{m}_t\left(\boldsymbol{a}_t, \varepsilon\right) = m_t + \int_{i\in\mathcal{F}} p_t^i s_t^i di - \int_{i\in\mathcal{F}} p_t^i \overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right) di \qquad (31)
$$

and

$$
[\overline{s}_t^i\left(\boldsymbol{a}_t, \varepsilon\right)]_{i\in\mathcal{F}} = \arg\max_{[\overline{s}_t^i]_{i\in\mathcal{F}}} \left[\int_{i\in\mathcal{F}} \left(\varepsilon - \varepsilon_t^{i*}\right) r_t^{K,i} \overline{s}_t^i di\right] \qquad (32)
$$

$$
\begin{aligned}
\text{s.t. } \int_{i\in\mathcal{F}} p_t^i \overline{s}_t^i di &\leq m_t + \int_{i\in\mathcal{F}} p_t^i s_t^i di \qquad (33) \\
0 &\leq \overline{s}_t^i \text{ for all } i \in \mathcal{F}. \qquad (34)
\end{aligned}
$$

Thus, the investor's post-trade holding of equity of firm $i \in \mathcal{F}$ (i.e., the solution to (32)-(34)), is given by the expression in part (i) of the statement of the lemma. Condition (22) is just (31). Condition (23) is obtained from (30) and (31). Condition (24) folllows from (21) and (31). ■

Lemma 3. *The value function* $V_t(\boldsymbol{a}_t, \varepsilon)$ *in (3) can be written as*

$$\begin{aligned} V_t(\boldsymbol{a}_t, \varepsilon) &= \int_{i\in\mathcal{F}} \left\{ \left[\varepsilon r_t^{K,i} + \pi \bar{\psi}_t^i \right] s_t^i + \bar{\psi}_{t+1}^i (1-\pi) S_t^i + b_t^i \right\} di \\ &\quad + \phi_t m_t + T_t + W_t^0 \\ &\quad + \alpha\theta \int_{i\in\mathcal{F}} (\varepsilon - \varepsilon_t^{i*}) r_t^{K,i} \left[\bar{s}_t^i(\boldsymbol{a}_t, \varepsilon) - s_t^i \right] di. \end{aligned} \tag{35}$$

Proof. The value function (3) can be written as

$$V_t(\boldsymbol{a}_t, \varepsilon) = \int_{i\in\mathcal{F}} \varepsilon r_t^{K,i} s_t^i di + W_t\left(\boldsymbol{a}_t'(\boldsymbol{a}_t, \varepsilon), 0\right) + \alpha \Gamma_t(\boldsymbol{a}_t, \varepsilon),$$

where

$$\boldsymbol{a}_t'(\boldsymbol{a}_t, \varepsilon) \equiv (m_t, [b_t^i]_{i\in\mathcal{F}}, [\pi s_t^i + (1-\pi) S_t^i]_{i\in\mathcal{F}}).$$

With (19),

$$W_t\left(\boldsymbol{a}_t'(\boldsymbol{a}_t, \varepsilon), 0\right) = \phi_t m_t + \int_{i\in\mathcal{F}} \{\bar{\psi}_t^i [\pi s_t^i + (1-\pi) S_t^i] + b_t^i\} di + T_t + W_t^0. \tag{36}$$

With (24) and (36), $V_t(\boldsymbol{a}_t, \varepsilon)$ can be written as (35). ■

Corollary 1. *The value function* $V_t(\boldsymbol{a}_t, \varepsilon)$ *in (35) can be written as*

$$\begin{aligned} V_t(\boldsymbol{a}_t, \varepsilon) &= \int_{i\in\mathcal{F}} \left\{ \left[\varepsilon r_t^{K,i} + \pi \bar{\psi}_t^i \right] s_t^i + \bar{\psi}_t^i (1-\pi) S_t^i + b_t^i \right\} di \\ &\quad + \phi_t m_t + T_t + W_t^0 \\ &\quad + \alpha\theta \Bigg\{ \mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}} \vartheta_t^*(\varepsilon) m_t \\ &\quad - \int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}} + \mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)=0\}} \right] \vartheta_t^i(\varepsilon) p_t^i s_t^i di \\ &\quad + \int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}} \mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}} \left[\vartheta_t^*(\varepsilon) - \vartheta_t^i(\varepsilon) \right] p_t^i s_t^i di \Bigg\}. \end{aligned} \tag{37}$$

Proof. Notice that

$$\begin{aligned} \vartheta_t^i(\varepsilon) &= \vartheta_t^*(\varepsilon) = 0 \\ &\Rightarrow i \in \mathcal{F}_t^*(\varepsilon) \text{ and } \varepsilon - \varepsilon_t^{i*} = 0, \end{aligned} \tag{38}$$

and

$$\begin{aligned} 0 &< \vartheta_t^*(\varepsilon) = \vartheta_t^i(\varepsilon) \\ &\Rightarrow i \in \mathcal{F}_t^*(\varepsilon), 0 < \varepsilon - \varepsilon_t^{i*}, \text{ and } \frac{(\varepsilon - \varepsilon_t^{i*}) r_t^{K,i}}{p_t^i} = \frac{(\varepsilon - \varepsilon_t^{s*}) r_t^{K,s}}{p_t^s} \text{ for all } i, s \in \mathcal{F}_t^*(\varepsilon). \end{aligned} \tag{39}$$

With (38), (39), and part (i) of Lemma 2, we have

$$
\begin{aligned}
& \int_{i\in\mathcal{F}} (\varepsilon-\varepsilon_t^{i*}) r_t^{K,i}\left[\overline{s}_t^i(\boldsymbol{a}_t,\varepsilon)-s_t^i\right] di \\
= & \int_{i\in\mathcal{F}} \mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}(\varepsilon-\varepsilon_t^{i*}) r_t^{K,i}\left[\overline{s}_t^i(\boldsymbol{a}_t,\varepsilon)-s_t^i\right] di \\
& +\int_{i\in\mathcal{F}} \mathbb{I}_{\{\vartheta_t^*(\varepsilon)=0\}}\left(\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}+\mathbb{I}_{\{\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}\right)(\varepsilon-\varepsilon_t^{i*}) r_t^{K,i}\left[\overline{s}_t^i(\boldsymbol{a}_t,\varepsilon)-s_t^i\right] di \\
& +\int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\left(\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}+\mathbb{I}_{\{\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}\right)(\varepsilon-\varepsilon_t^{i*}) r_t^{K,i}\left[\overline{s}_t^i(\boldsymbol{a}_t,\varepsilon)-s_t^i\right] di \\
= & \int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}+\mathbb{I}_{\{0\le\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}\right](\varepsilon_t^{i*}-\varepsilon) r_t^{K,i} s_t^i di \\
& +\int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}(\varepsilon-\varepsilon_t^{i*}) r_t^{K,i}\left[\overline{s}_t^i(\boldsymbol{a}_t,\varepsilon)-s_t^i\right] di \\
= & \int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}+\mathbb{I}_{\{0\le\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}+\mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}\right](\varepsilon_t^{i*}-\varepsilon) r_t^{K,i} s_t^i di \\
& +\vartheta_t^*(\varepsilon)\int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}} p_t^i \overline{s}_t^i(\boldsymbol{a}_t,\varepsilon) di \\
= & \int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}+\mathbb{I}_{\{0\le\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}+\mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}\right](\varepsilon_t^{i*}-\varepsilon) r_t^{K,i} s_t^i di \\
& +\mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\vartheta_t^*(\varepsilon)\int_{i\in\mathcal{F}} p_t^i \overline{s}_t^i(\boldsymbol{a}_t,\varepsilon) di \\
= & \int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}+\mathbb{I}_{\{0\le\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}+\mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}\right](\varepsilon_t^{i*}-\varepsilon) r_t^{K,i} s_t^i di \\
& +\mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\vartheta_t^*(\varepsilon)\left(m_t+\int_{i\in\mathcal{F}} p_t^i s_t^i di\right) \\
= & \int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}+\mathbb{I}_{\{0\le\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}+\mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}\right](\varepsilon_t^{i*}-\varepsilon) r_t^{K,i} s_t^i di \\
& +\int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}\vartheta_t^*(\varepsilon) p_t^i s_t^i di+\int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^i(\varepsilon)=\vartheta_t^*(\varepsilon)\}}(\varepsilon-\varepsilon_t^{i*}) r_t^{K,i} s_t^i di \\
& +\mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\vartheta_t^*(\varepsilon) m_t \\
= & -\int_{i\in\mathcal{F}} \left[\mathbb{I}_{\{\vartheta_t^*(\varepsilon)<0\}}+\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)=0\}}\right]\vartheta_t^i(\varepsilon) p_t^i s_t^i di \\
& +\int_{i\in\mathcal{F}} \mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_t^i(\varepsilon)<\vartheta_t^*(\varepsilon)\}}\left[\vartheta_t^*(\varepsilon)-\vartheta_t^i(\varepsilon)\right] p_t^i s_t^i di+\mathbb{I}_{\{0<\vartheta_t^*(\varepsilon)\}}\vartheta_t^*(\varepsilon) m_t.
\end{aligned}
$$

Together, the last equality and (35) imply (37). ■

Lemma 4. *Let* $\boldsymbol{a}_{t+1}=\left(m_{t+1},[b_{t+1}^i]_{i\in\mathcal{F}},[s_{t+1}^i]_{i\in\mathcal{F}}\right)$ *denote the portfolio chosen by an investor at the end of the first subperiod of period* t*. This portfolio must satisfy the following first-order* *necessary and sufficient conditions:*

$$0 \geq -1+\beta R_t^i, \text{ with } ``=" \text{ if } 0<b_t^i \tag{40}$$

$$0 \geq -\phi_t+\beta\left(\Lambda_{t+1}+\phi_{t+1}\right), \text{ with } ``=" \text{ if } 0<m_t \tag{41}$$

$$0 \geq -\psi_t^i+\beta\left[\bar{\varepsilon} r_{t+1}^{K,i}+\mathcal{R}_{t+1}^i+\pi\bar{\psi}_{t+1}^i\right], \text{ with } ``=" \text{ if } 0<s_{t+1}^i, \tag{42}$$

where

$$\Lambda_{t+1} \equiv \alpha\theta\int \mathbb{I}_{\{0<\vartheta_{t+1}^*(\varepsilon)\}}\vartheta_{t+1}^*(\varepsilon)\,dG(\varepsilon) \tag{43}$$

$$\begin{aligned}\mathcal{R}_{t+1}^i \equiv\ & \alpha\theta\int\Big[-[\mathbb{I}_{\{\vartheta_{t+1}^*(\varepsilon)<0\}}+\mathbb{I}_{\{\vartheta_{t+1}^i(\varepsilon)<\vartheta_{t+1}^*(\varepsilon)=0\}}]\vartheta_{t+1}^i(\varepsilon)\,p_{t+1}^i \\ & +\mathbb{I}_{\{0<\vartheta_{t+1}^*(\varepsilon)\}}\mathbb{I}_{\{\vartheta_{t+1}^i(\varepsilon)<\vartheta_{t+1}^*(\varepsilon)\}}\left[\vartheta_{t+1}^*(\varepsilon)-\vartheta_{t+1}^i(\varepsilon)\right]p_{t+1}^i\Big]dG(\varepsilon).\end{aligned} \tag{44}$$

Proof. With Corollary 1, and using (43) and (44),

$$\begin{aligned}\int V_t(\boldsymbol{a}_t,\varepsilon)\,dG(\varepsilon) =\ & (\Lambda_t+\phi_t)m_t+\int_{i\in\mathcal{F}}\left[\bar{\varepsilon} r_t^{K,i}+\mathcal{R}_t^i+\pi\bar{\psi}_t^i\right]s_t^i di+\int_{i\in\mathcal{F}} b_t^i di \\ & +\int_{i\in\mathcal{F}}\bar{\psi}_t^i(1-\pi)\,S_t^i di+T_t+W_t^0,\end{aligned}$$

so the maximization on the right side of (20) can be written as

$$\begin{aligned}\max_{m_{t+1},[b_{t+1}^i,s_{t+1}^i]_{i\in\mathcal{F}}} & \Bigg\{\int_{i\in\mathcal{F}}(-1/R_t^i+\beta)b_{t+1}^i di+\left[-\phi_t+\beta\left(\Lambda_{t+1}+\phi_{t+1}\right)\right]m_t \\ & +\int_{i\in\mathcal{F}}\left[-\psi_t^i+\beta\left[\bar{\varepsilon} r_{t+1}^{K,i}+\mathcal{R}_{t+1}^i+\pi\bar{\psi}_{t+1}^i\right]\right]s_{t+1}^i di+ \\ & \int_{i\in\mathcal{F}}\beta\bar{\psi}_{t+1}^i(1-\pi)\,S_{t+1}^i di+\beta\left(T_{t+1}+W_{t+1}^0\right)\Bigg\}.\end{aligned}$$

Conditions (40), (41), and (42), are the first-order condition with respect to b_{t+1}^i, m_{t+1}, and s_{t+1}^i, respectively. ■

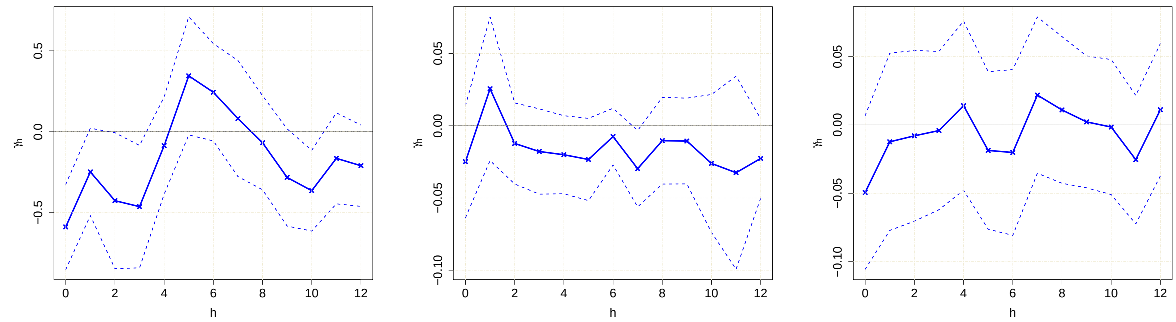
B. Appendix: data, additional regressions, and robustness

B.1. Data

To be added ...

B.2. Additional regressions

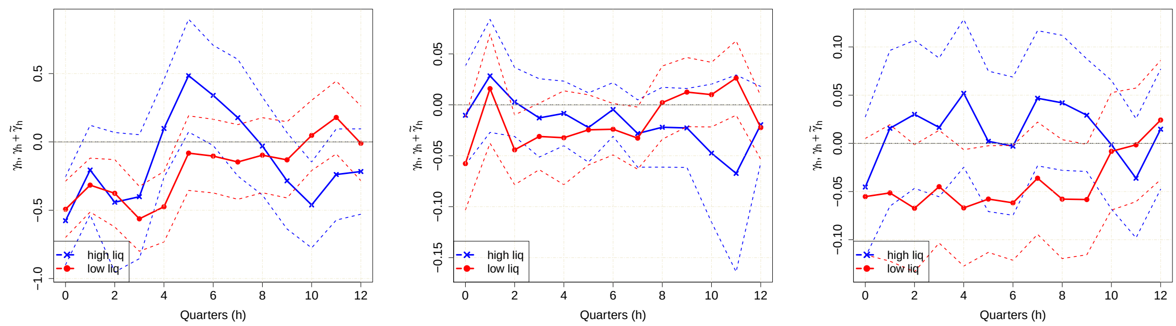
B.2.1. Additional reduced form regressions



(a) $y^i_{t+h} = \log(q^i_{t+h})$ (b) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (c) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_h from estimating specification (6) with y^i_{t+h} as the dependent variable, controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 6: Heterogeneity in responses to monetary policy shock conditional on stock turnover, non-cumulated responses

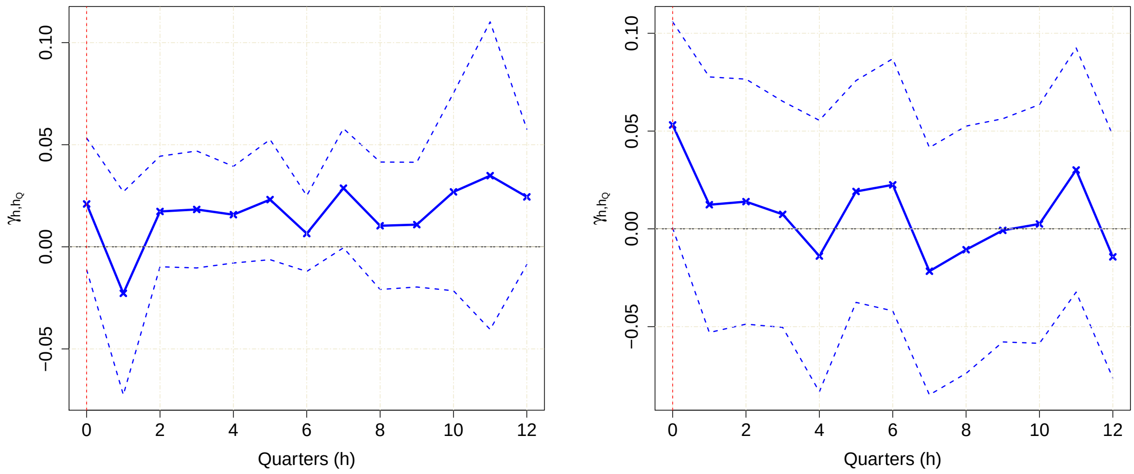


(a) $y^i_{t+h} = \log(q^i_{t+h})$ (b) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (c) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from estimating specification (7) with y^i_{t+h} as the dependent variable, controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 7: Heterogeneity in responses to monetary policy shock conditional on stock turnover, across liquidity ratio groups, non-cumulated responses

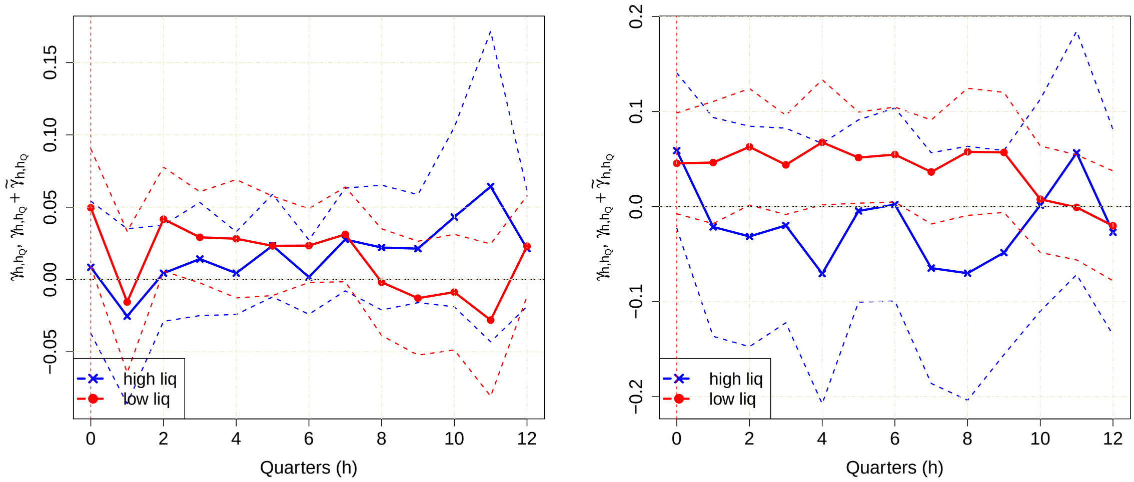
B.2.2. Additional IV regressions



(a) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (b) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_{h,h_q} from estimating specification (8) with y^i_{t+h} as the dependent variable, controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Vertical red dashed line marks the value of $h_q = 0$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 8: Issuances and investment predicted by instrumented q, non-cumulated responses



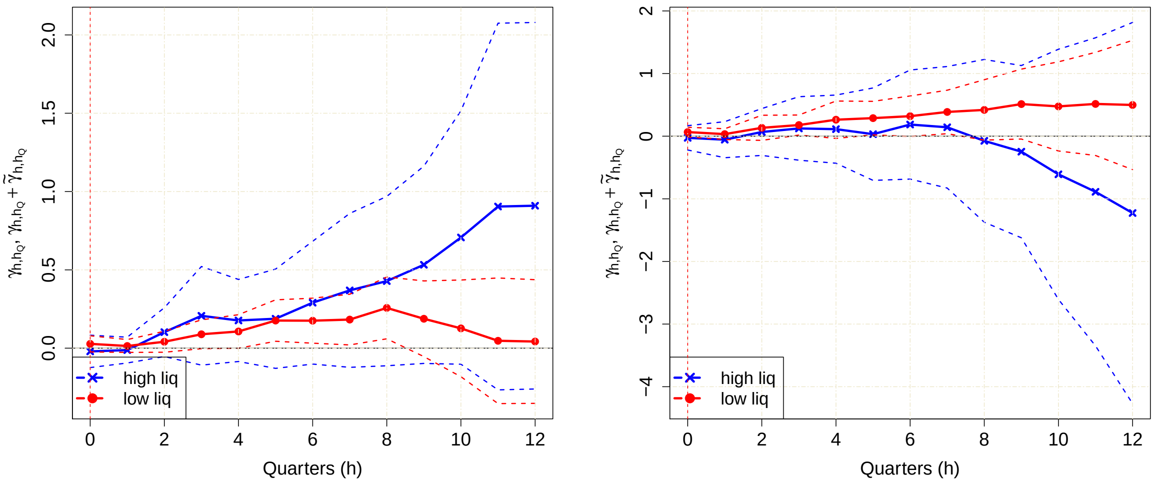
(a) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (b) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_{h,h_q} and $\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q}$ from estimating specification (9) with y^i_{t+h} as dependent variable, controlling for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Vertical red dashed line marks the value of $h_q = 0$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 9: Issuances and investment predicted by instrumented q, across liquidity ratio groups, non-cumulated responses

B.3. Robustness of regression estimates

Figure 10: Issuances and investment predicted by instrumented q, across liquidity ratio groups, with additional firm controls

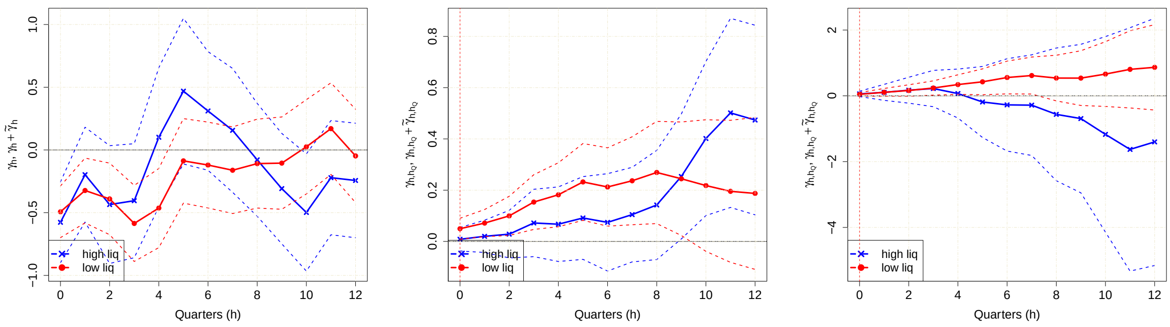


(a) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} E^i_{t+s}\right) / B^i_{t-1}$ (b) $\tilde{y}^i_{t+h} = \left(\sum_{s=0}^{h} I^i_{t+s}\right) / K^i_{t-1}$

Notes: Point estimates and 95% confidence intervals for γ_{h,h_q} and $\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q}$ from estimating specification

$$\tilde{y}^i_{t+h} = f^i_h + d_{s,h,t+h} + \alpha_h \mathbb{I}^i_{L,t-1} + \left(\rho_h + \tilde{\rho}_h \mathbb{I}^i_{L,t-1}\right) y^i_{t-1} + \left(\Lambda_h + \tilde{\Lambda}_h \mathbb{I}^i_{L,t-1}\right) Z^i_{t-1} + \left(\Psi_h + \tilde{\Psi}_h \mathbb{I}^i_{L,t-1}\right) Z^i_{t-1}\varepsilon^m_t$$
$$+ \left(\beta_h + \tilde{\beta}_h \mathbb{I}^i_{L,t-1}\right) x^i_{t-1} + \left(\gamma_{h,h_q} + \tilde{\gamma}_{h,h_q} \mathbb{I}^i_{L,t-1}\right) \log\left(q^i_{t+h_q}\right) + u^i_{h,t+h}$$

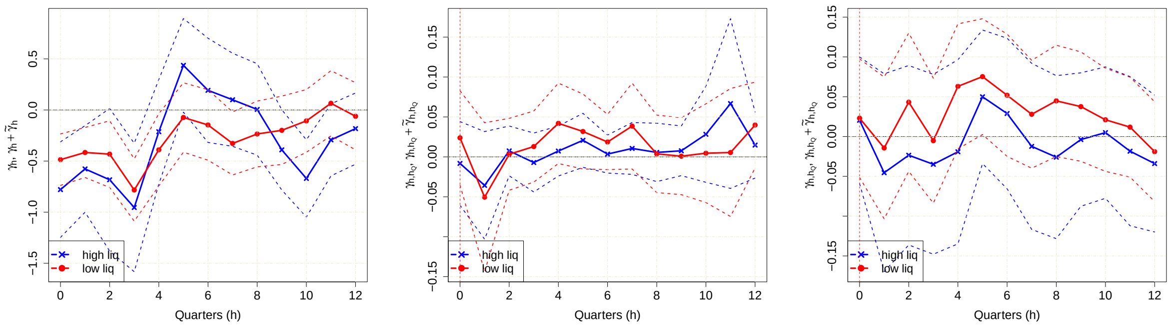
where Z^i_t is a vector containing the firm's age, liquidity ratio, $\log(B^i_t)$ as a measure of firm size, and $\frac{\text{total debt}^i_t}{\text{total assets}^i_t}$ as a measure of leverage. $\log\left(q^i_{t+h_q}\right)$ is instrumented with $x^i_{t-1}\varepsilon^m_t$. The specification also controls for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Vertical red dashed line marks the value of $h_q = 0$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.



(a) $y^i_{t+h} = \log(q^i_{t+h})$ (b) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (c) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from estimating specification (7) in panel (a), and specification (9) in panels (b) and (c) with $y_{i,t+h}$ as dependent variable. The specification does not control for $\hat{u}^i_{h-1,t+h-1}$ at any h. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

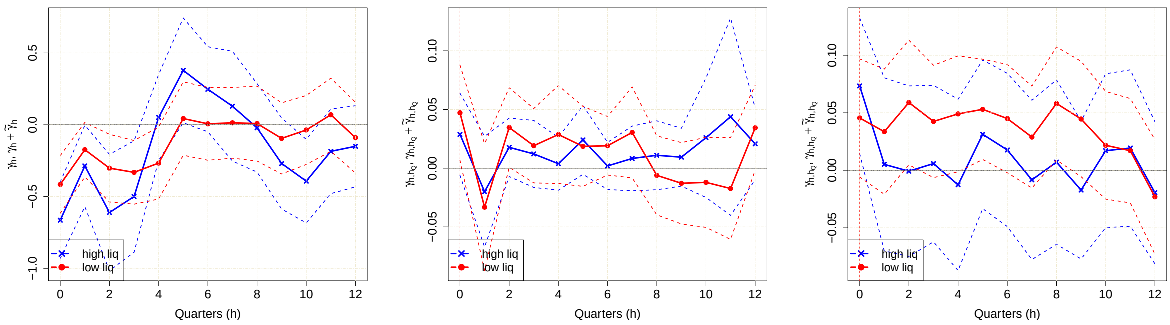
Figure 11: OLS and IV regression estimates, across liquidity ratio groups, not including residuals of horizon $h-1$ local projection as regressors



(a) $y^i_{t+h} = \log(q^i_{t+h})$ (b) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (c) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from estimating specification (7) in panel (a), and specification (9) in panels (b) and (c) with $y_{i,t+h}$ as dependent variable. ε^m_t is the median shock series inferred based on the VAR of Jarociński and Karadi (2019), for 1990Q1–2007Q4. The specification also controls for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 12: OLS and IV regression estimates, across liquidity ratio groups, given Jarociński and Karadi (2019) shock series, non-cumulated responses



(a) $y^i_{t+h} = \log(q^i_{t+h})$ (b) $y^i_{t+h} = E^i_{t+h}/B^i_{t+h-1}$ (c) $y^i_{t+h} = I^i_{t+h}/K^i_{t+h-1}$

Notes: Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from estimating specification (7) in panel (a), and specification (9) in panels (b) and (c) with $y_{i,t+h}$ as dependent variable. ε^m_t is the median shock series inferred based on the 'poor man's sign restrictions' of Jarociński and Karadi (2019), for 1990Q1–2016Q4. The specification also controls for $\hat{u}^i_{h-1,t+h-1}$ when $h \geq 1$. Confidence intervals constructed based on two-way clustered standard errors at firm and industry-quarter levels.

Figure 13: OLS and IV regression estimates, across liquidity ratio groups, given Jarociński and Karadi (2019) 'poor man's sign restrictions', non-cumulated responses