Q-Monetary Transmission

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We study the effects of monetary policy–induced changes in Tobin's q on corporate investment and capital structure. We develop a theory of the mechanism, provide empirical evidence, evaluate the ability of the quantitative theory to match the evidence, and quantify the relevance for monetary transmission to aggregate investment.

I. Introduction

The chain of causal links that lie between monetary policy actions and their ultimate effects on macroeconomic variables is broadly referred to as the monetary transmission mechanism. Since the immediate effect of these actions is to influence a wide array of interest rates and prices of financial and nonfinancial assets, it is easy to imagine many ways in which

We thank Sebastián Fanelli, Pascal Paul, and Ander Pérez-Orive for their useful discussions. We also thank Vladimir Asriyan, Isaac Baley, Jordi Galí, Victoria Vanasco, and Jaume Ventura for their feedback. Priit Jeenas acknowledges financial support via the Juan de la Cierva Formación Grant (FJC2019-041561) from the Spanish Ministry of Science, Innovation, and Universities, from the Plan Estatal de Investigación Científica y Técnica y de Innovación 2017–20 (PID2020-116268GB-I00), and from the Spanish Ministry of Economy and Competitiveness, through the Severo Ochoa Programme for Centres of Excellence in research and development (CEX2019-000915-S). This paper was edited by Andrew Atkeson.

Electronically published February 1, 2024

Journal of Political Economy, volume 132, number 3, March 2024.

https://doi.org/10.1086/726904

monetary policy may affect economic decisions. Consequently, textbook treatments contain extensive taxonomies of a myriad of monetary transmission mechanisms.[1] For investment, 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 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 (as described, e.g., by 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 decrease in the nominal policy rate causes stock prices to rise (as is well documented empirically by, e.g., Bernanke and Kuttner 2005) relative to the replacement cost of capital. Then, since the market yield of the stock is a key determinant of the cost of external financing in capital markets, equity-financed investment should increase as a result of the monetary policy action (e.g., as conjectured by Keynes 1936/1973 and Tobin 1969).[3] The credit channel is best described as an amplification mechanism associated with 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 on debt (Bernanke and Gertler 1989) or tightening of borrowing constraints (Kiyotaki and Moore 1997) imply debt-financed investment should fall as a result of the monetary policy action.

The user cost channel is well understood and present in most quantitative models used for policy analysis. The credit channel has received much attention in the past decade and is now standard in theoretical and quantitative policy-oriented modeling. The asset price channel is discussed in undergraduate textbooks and policy circles, but academic research on it is scant. In this paper, we study the effects of changes in Tobin's q induced by monetary policy actions—a mechanism we dub "q-monetary transmission" or the "q-channel"—and take several steps toward (re-)establishing Tobin's q as a prominent causal link between monetary policy and the real economy. Specifically, we (i) develop a model of the q-monetary

[1] See, e.g., Mishkin (1995, 1996, 2001) and Boivin, Kiley, and Mishkin (2010).

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

[3] Keynes (1936/1973) argued that stock market (re)valuations "inevitably exert a decisive influence on the rate of current investment" (151). Tobin (1969) elaborated on this idea by emphasizing stock market revaluations driven by monetary policy and introduced the now famous "q" to formalize this specific transmission mechanism.

transmission mechanism; (ii) provide identification and empirical evidence for the q-channel; (iii) evaluate the ability of the quantitative theory to match the evidence; and (iv) quantify the effect of q-monetary transmission on firms' investment and capital structure.

On the theory front, we develop a model that clarifies the roles that financial constraints, the stock market, and money play in the transmission of monetary policy to firms' investment and financing decisions through stock prices. Stock market turnover among outside financial investors with heterogeneous valuations generates a "bubble-like" resale-value component through which monetary policy affects the market price of a firm's stock. In turn, the investment and capital structure decisions of firms that rely on equity as a source of external financing respond to exogenous (policy-induced) variation in the market price of their equity.

On the empirical front, the main challenge for estimating the q-channel is that monetary policy may affect investment and stock prices through other channels. For instance, a contractionary money shock may lead to a joint reduction in a firm's stock price and investment through the traditional interest rate channel (i.e., due to higher discounting), but the reduction in the stock price is not causing the reduction in investment. Thus, we cannot hope to estimate the causal effect of the stock price on investment—the hallmark of the q-channel—simply from the comovement of investment and the stock price induced by monetary policy shocks.

We meet this empirical challenge by exploiting stock turnover as a source of cross-sectional variation in the responsiveness of stock prices to monetary shocks.[4] Our empirical strategy builds on the idea that as long as stock turnover (and any unobserved firm-level characteristic that is correlated with turnover) does not affect the responsiveness to money shocks of other transmission variables that influence the outcome variable, then identified money shocks combined with heterogeneity in cross-sectional stock turnover can be used as a source of exogenous (policy-driven) cross-sectional variation in Tobin's q. We use this cross-sectional variation in the responses of stock prices to money shocks across firms with different stock turnover to identify the effects of changes in stock prices on firms' investment and capital structure decisions. Specifically, we construct an instrument for firm-level Tobin's q by interacting monetary policy shocks with a (predetermined) measure of firm-specific stock turnover. We find that such instrumented variation in Tobin's q has significant persistent effects on the equity issuance and investment decisions of firms

[4] Lagos and Zhang (2020) provide evidence that stock turnover is a strong predictor of the cross-sectional differences in the responsiveness of stock prices to monetary policy shocks.

whose balance sheets have a relatively low liquidity ratio (defined as the share of liquid assets in total assets). For example, for firms with below-median liquidity ratios, a 1% increase in Tobin's q causes (i) a 0.08 percentage point increase in the firm's ratio of net equity issuance relative to the book value of total assets in the quarter of the monetary shock and (ii) a response of approximately 1% higher investment rate at the 2-quarter horizon. Our microestimates imply that the q-channel accounts for about one-third of the conventional estimates of the peak response of aggregate investment to monetary policy shocks. The main findings are robust to controlling for firm and stock characteristics that may be correlated with turnover and could potentially affect the responsiveness of the firm's equity issuance or investment through transmission channels other than Tobin's q.

Our work makes contact with three literatures. First, we contribute to the literature on monetary transmission by filling the empirical and theoretical void on the asset price channel that operates through Tobin's q, as originally proposed by Tobin (1969). Second, we contribute to the literature on the causal effects of changes in stock market valuations on corporate investment decisions (e.g., Keynes 1936/1973; Brainard and Tobin 1968; Tobin 1969; Tobin and Brainard 1976; Fischer and Merton 1984; Morck et al. 1990; Blanchard, Rhee, and Summers 1993; Baker, Stein, and Wurgler 2003; Gilchrist, Himmelberg, and Huberman 2005; Polk and Sapienza 2008; Amihud and Levi 2022). Our contribution to this literature is twofold. On the theory front, we develop an equilibrium model with two sectors: a productive sector, where firms are managed by entrepreneurs who make investment and equity issuance decisions, and a financial sector, based on Lagos and Zhang (2020), where money and equity claims to the capital installed in the firm are traded among investors with heterogeneous valuations of the marginal product of firms' capital. Our theory highlights the roles that financial constraints (as a determinant of a firm's dependence on equity financing) and heterogeneous valuations of capital play in the transmission of monetary policy shocks to investment decisions through stock prices. On the empirical front, we provide estimates of the causal effect of changes in stock prices on firms' financing and investment decisions. Relative to existing work, our contribution is to address the common endogeneity concerns of regressing investment on Tobin's q by proposing an instrument for changes in Tobin's q that are not caused by firm-level changes in marginal q. As mentioned above, our innovation in this regard consists of exploiting a combination of identified monetary policy shocks and the cross-sectional variation in the responsiveness of stock prices to these shocks due to (predetermined) differences in stock turnover. Third, our theoretical and empirical results on the response of firms' equity issuance and capital structure 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; Korajczyk and Levy 2003; Hovakimian, Hovakimian, and Tehranian 2004; Acharya, Byoun, and Xu 2020). Our contribution to this literature is to identify the persistent effects of monetary policy shocks on the capital structure of public firms.

II. Theory

Time is represented by a sequence of periods indexed by $t \in \{0, 1, ...\}$. Each time period is divided into 2 subperiods where different activities take place. There is a continuum of infinitely lived agents of two types: investors, each identified with a point in the set $\mathcal{I} = [0, 1]$, and brokers, each identified with a point in the set $\mathcal{B} = [0, 1]$. There is a continuum (with unit measure) of entrepreneurs (also referred to as firms) who live for a random number of periods. Each entrepreneur who is alive at the beginning of period t is identified with a point in the set $\mathcal{E}_t \subset \mathbb{R}_+$. A fraction $1 - \pi \in [0, 1]$ of the population of entrepreneurs in the set $\mathcal{E}_t$ dies (i.e., exits the economy) at the beginning of the second subperiod of period t. The subset of entrepreneurs who exit 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 be consumed only in the first and second subperiods, respectively. Capital is storable but depreciates at rate $\delta \in [0, 1]$ between periods. Upon entering the economy, an entrepreneur is endowed with $w_0^i \in \mathbb{R}_+$ units of good 2 and $k_0 \in \mathbb{R}_+$ units of capital. We use a cumulative distribution function Ω to describe the heterogeneity in the initial endowment of (claims to) good 2 relative to capital, $\omega_0^i \equiv w_0^i/k_0$, across entrepreneurs. 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, which can be managed only by entrepreneurs. One of these production technologies 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 operated by an entrepreneur delivers zk_t units of good 1 at the end of the first subperiod of t, with $z \in \mathbb{R}_{++}$. The other 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 $t + 1$. This technology is represented by a cost function,

$C(x_t, k_t) \equiv x_t + \Psi(x_t/k_t)k_t$, interpreted as the cost (in terms of good 2) of producing and installing x_t units of capital for an entrepreneur whose current capital is k_t. We assume $0 < \Psi''$ and that there is a $\iota_0 \in \mathbb{R}_+$ such that $\Psi(\iota_0) = \Psi'(\iota_0) = 0$. It is convenient to define $c(x_t/k_t) \equiv C(x_t, k_t)/k_t$, that is, the cost of investment per unit of installed capital. The assumptions on Ψ imply $c(\iota_0) - \iota_0 = c'(\iota_0) - 1 = 0 < c''(\cdot)$. Once installed, capital is entrepreneur specific; that is, capital installed by entrepreneur i is productive only 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 to the future returns from the newly created capital. Entrepreneurs are also allowed to sell equity claims on any existing capital they currently own. An equity share issued by an entrepreneur in the second subperiod of t represents ownership of 1 unit of capital along with the stream of dividends of good 1 produced by that unit of capital. When an entrepreneur dies, the outstanding equity claims they had previously issued disappear, and k_0 units of the capital that the entrepreneur used to manage are distributed to newly born entrepreneurs.[5] There are two other financial instruments: a real 1-period pure-discount government bond and money. A unit of the bond issued in the second subperiod of t represents a risk-free claim to 1 unit of good 2 in the second subperiod of $t + 1$. The stock of bonds outstanding at time t is denoted 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 nominal money supply at the beginning of period t is denoted A_t^m, and we assume $A_{t+1}^m = \mu A_t^m$, with $\mu \in \mathbb{R}_{++}$ and $A_0^m \in \mathbb{R}_{++}$ 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.[6]

The market structure is as follows. In the second subperiod, all agents can trade good 2, equity shares, bonds, and money, in a spot Walrasian market.[7] In the first subperiod, investors can trade equity shares and

[5] Any financial claims owned by the entrepreneur are distributed uniformly (lump sum) to investors.

[6] We assume brokers do not hold financial assets. 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, 2020) for a treatment of the broker's portfolio problem in this class of models.

[7] 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 nontradable. The idea is that, once installed by an entrepreneur, physical capital becomes entrepreneur-specific and cannot be operated by another entrepreneur. An

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 interbroker 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.[8] The timing is that the round of OTC trade takes place in the first subperiod and ends before equity pays out first-subperiod dividends.[9] 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.[10]

A broker's preferences are given by

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

where $\beta \in (0, 1)$ is the discount factor, and y_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.[11] The expectation operator, $\mathbb{E}_0^B$, is with respect to the probability measure induced by the random trading process in the OTC market. An investor's preferences are given by

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

entrepreneur can, however, disinvest (which entails bearing the adjustment cost, Φ) to turn installed capital into good 2, which can then be traded freely in the Walrasian market.

[8] This is the specification used in Lagos and Zhang (2020). 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 (2020) simplifies the exposition without affecting the mechanisms of interest.

[9] As in previous search models of OTC markets, e.g., Duffie, Gârleanu, and Pedersen (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.

[10] See Lagos and Zhang (2019) for a similar model where investors can buy equity with margin loans.

[11] Dealers get no utility from good 1, so they have no motive for purchasing equity on their own account in the first subperiod. This assumption is easy to relax, but we adopt it because it is the standard benchmark in the search-based OTC literature, e.g., see Duffie, Gârleanu, and Pedersen (2005), Weill (2007), Lagos and Rocheteau (2009), or Lagos, Rocheteau, and Weill (2011).

where y_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 c_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 for good 1 that is distributed independently over time and across investors with a differentiable cumulative distribution function G with support $[\varepsilon_L, \varepsilon_H] \subseteq [0, \infty]$ and mean $\bar{\varepsilon} \equiv \int \varepsilon dG(\varepsilon)$. 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 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

$$\sum_{j=t}^{\infty} (\beta\pi)^{(j-t)} \left(y_j + \beta\varepsilon_e c_{j+1}\right),$$

where y_j denotes consumption of good 2 in the second subperiod of period j, $\varepsilon_e \in \mathbb{R}_{++}$ is the entrepreneur's valuation of their own production of good 1, and c_{j+1} is the quantity of this good consumed at the end of the first subperiod of period $j + 1$.

A. Equilibrium

The model consists of a financial sector, in which investors make optimal portfolio decisions, and an investment sector, in which entrepreneurs make optimal investment and capital structure decisions. Next, we formulate these decision problems.

Let $\boldsymbol{\phi}_t \equiv (\phi_t^b, \phi_t^m, \phi_t^s)$ denote asset prices in the competitive market of the second subperiod of period t, where ϕ_t^b is the real price of a newly issued government bond, ϕ_t^m is the real price of a unit of money, and ϕ_t^s is the real price of an equity share (all expressed in terms of good 2). At this time, an investor with portfolio $\boldsymbol{a} \in \mathbb{R}_+^3$ who negotiated a fee $\varpi \in \mathbb{R}_+$ with a broker in the previous subperiod chooses consumption of good 2, y_t, labor supply, h_t, and portfolio of assets, $\boldsymbol{a}_{t+1} \equiv (a_{t+1}^b, a_{t+1}^m, a_{t+1}^s)$, to solve

$$W_t(\boldsymbol{a}, \varpi) = \max_{(y_t, h_t, \boldsymbol{a}_{t+1}) \in \mathbb{R}_+^5} \Bigg[y_t - h_t + \beta \int \{\varepsilon z a_{t+1}^s + \alpha \bar{\Gamma}_t(\boldsymbol{a}_{t+1}, \varepsilon) + W_{t+1}[\boldsymbol{a}'(\boldsymbol{a}_{t+1}), 0]\} dG(\varepsilon) \Bigg]$$

$$\text{s.t. } y_t + \boldsymbol{\phi}_t \boldsymbol{a}_{t+1} \leq \boldsymbol{\phi}_t' \boldsymbol{a} + h_t - \varpi + T_t,$$

where $\boldsymbol{a}'(\boldsymbol{a}_t) \equiv (a_t^b, a_t^m, \pi(1-\delta)a_t^s)$, $\boldsymbol{\phi}_t' \equiv (1, \phi_t^m, \phi_t^s)$, $T_t \in \mathbb{R}$ is the real value of the lump-sum government transfer, and $\bar{\Gamma}_{t+1}(\boldsymbol{a}_{t+1}, \varepsilon)$ is the gain from trade that an investor with beginning-of-period portfolio $\boldsymbol{a}_{t+1}$ and valuation ε obtains in a bilateral bargain with a broker in the first subperiod of period $t+1$.[12]

Let $J_t(\boldsymbol{b}_t)$ denote the maximum expected discounted payoff at the beginning of the second subperiod of period t of an entrepreneur who currently has balance sheet $\boldsymbol{b}_t \equiv (a_t^b, k_t, s_t)$, composed of (claims to) a_t^b units of good 2, installed capital k_t, and s_t outstanding equity claims on installed capital. The value function satisfies

$$J_t(\boldsymbol{b}_t) = \max_{y_t, a_{t+1}^b, e_t, x_t} \{y_t + \beta[\varepsilon_e z(k_{t+1} - s_{t+1}) + \pi J_{t+1}(\boldsymbol{b}_{t+1})]\} \tag{1}$$

$$\text{s.t. } y_t + \mathrm{c}(x_t/k_t)k_t + \phi_t^b a_{t+1}^b \le \phi_t^s e_t + a_t^b, \tag{2}$$

$$k_{t+1} = (1-\delta)k_t + x_t, \tag{3}$$

$$s_{t+1} = (1-\delta)s_t + e_t, \tag{4}$$

$$s_{t+1} \in [0, k_{t+1}], \tag{5}$$

$$y_t, a_{t+1}^b \in \mathbb{R}_+, \tag{6}$$

where $\boldsymbol{b}_{t+1} \equiv (a_{t+1}^b, k_{t+1}, s_{t+1})$, y_t denotes consumption of good 2, x_t is the quantity of newly created capital, and e_t is the number of newly issued equity shares. Condition (2) is the entrepreneur's budget constraint (expressed in terms of good 2), while (3) and (4) are the laws of motion for the stock of installed capital and outstanding equity shares on the entrepreneur's installed capital, respectively. The condition $0 \le s_{t+1}$ in (5) states that an entrepreneur cannot buy claims on her own dividend of good 1 issued by other agents. The condition $s_{t+1} \le k_{t+1}$ in (5) states that entrepreneurs cannot sell claims on capital that are not backed by capital owned by the entrepreneur; that is, equity issuance must satisfy $e_t \le x_t + (1-\delta)(k_t - s_t)$. The nonnegativity constraints in (6) rule out negative consumption of good 2 and short positions in the government bond.[13]

[12] Let $[\bar{\boldsymbol{a}}_t(\boldsymbol{a}_t, \varepsilon), \varpi_t(\boldsymbol{a}_t, \varepsilon)]$ denote the bargaining outcome between a broker and an investor with portfolio $\boldsymbol{a}_t$ and valuation ε in the first subperiod of period t, where $\varpi_t(\boldsymbol{a}_t, \varepsilon)$ is the broker's fee, and $\bar{\boldsymbol{a}}_t(\boldsymbol{a}_t, \varepsilon) \equiv (\bar{a}_t^b(\boldsymbol{a}_t, \varepsilon), \bar{a}_t^m(\boldsymbol{a}_t, \varepsilon), \bar{a}_t^s(\boldsymbol{a}_t, \varepsilon))$ is the investor's post-trade portfolio of bonds, money, and equity. Then we can write the investor's corresponding gain from trade as $\bar{\Gamma}_t(\boldsymbol{a}_t, \varepsilon) \equiv \varepsilon z[\bar{a}_t^s(\boldsymbol{a}_t, \varepsilon) - a_t^s] + W_t[\bar{\boldsymbol{a}}_t'(\boldsymbol{a}_t, \varepsilon), \varpi_t(\boldsymbol{a}_t, \varepsilon)] - W_t[\boldsymbol{a}'(\boldsymbol{a}_t), 0]$, where $\bar{\boldsymbol{a}}_t'(\boldsymbol{a}_t, \varepsilon) \equiv (\bar{a}_t^b(\boldsymbol{a}_t, \varepsilon), \bar{a}_t^m(\boldsymbol{a}_t, \varepsilon), \pi(1-\delta)\bar{a}_t^s(\boldsymbol{a}_t, \varepsilon))$. We provide a full characterization of the bargaining outcome in lemma 1 (app. A; apps. A–E are available online).

[13] The formulation (1) assumes an entrepreneur does not hold money. This assumption merely simplifies the exposition. In this environment, entrepreneurs are not involved in transactions for which money is used as a medium of exchange, so we can anticipate they will never choose to carry cash given they have the option to hold interest-bearing government bonds. In our empirical work, we will combine cash and "money-like" short-term financial investments (e.g., Treasuries) into a single asset category called liquid assets.

An equilibrium consists of asset prices and individual entrepreneur and investor decisions, such that (i) individual decisions are optimal given prices and (ii) prices clear markets given the optimal decisions.[14] In the following section, we use an analytical characterization of equilibrium prices and allocations to build intuition for the workings of the theory.

B. *Analytical Results*

We focus on stationary monetary equilibria in which the aggregate supply of equity, aggregate real money balances, and real equity prices are constant over time; that is, $S_t = S$, $\phi_t^m A_t^m \equiv \mathrm{M}_t = \mathrm{M}$, $\phi_t^s = \phi^s \equiv \varphi^s z$, and $p_t \phi_t^m = \bar{\varphi}^s z$, for all t. In this section, we assume $\pi = 0$ (entrepreneurs live for 1 period) in order to derive the main theoretical insights analytically.[15]

To characterize the equilibrium, it is useful to define the marginal stock market valuation in the first subperiod of t, $\varepsilon_t^* \equiv p_t \phi_t^m / z$, and the nominal interest rate between period t and $t+1$,

$$r_{t+1} \equiv \frac{\phi_t^m}{\beta \phi_{t+1}^m} - 1. \tag{7}$$

The marginal valuation ε_t^* is the one that makes an investor indifferent to whether to hold equity or sell it for cash in the first subperiod.[16] The nominal interest rate r_{t+1} is the nominal yield of a 1-period risk-free nominal bond issued in the second subperiod of t and redeemed in the second subperiod of $t+1$ that is illiquid in the sense that it cannot be used to purchase stocks in the first subperiod of $t+1$. In a stationary equilibrium with $\pi = 0$, $\varepsilon_t^* = \varepsilon^* \equiv \bar{\varphi}^s$ for all t. Also, $r_{t+1} = r \equiv (\mu - \beta)/\beta$ for all t, so we regard r as the nominal policy rate, which can be implemented by changing the growth rate in the money supply, μ.

The following proposition gives a full characterization of the stationary monetary equilibrium for the economy with $\pi = 0$. Before stating the results, it is useful to introduce some notation. For any $\phi \in \mathbb{R}_+$, let $\iota(\phi)$ be the investment rate that solves $\mathrm{c}'(\iota) = \phi$, and define $\iota_s \equiv \iota(\phi^s)$ and $\iota_e \equiv \iota(\phi_e^s)$, where $\phi_e^s \equiv \beta \varepsilon_e z$. Intuitively, ϕ_e^s represents the entrepreneur's marginal private value of capital, while ϕ^s represents the marginal market value of capital to the outside investors who price the entrepreneur's equity.

Proposition 1. Let $\bar{r} \equiv \alpha\theta(\bar{\varepsilon} - \varepsilon_L)/\varepsilon_L$. For each $r \in (0, \bar{r})$, there exists a unique stationary monetary equilibrium.

[14] We provide a more formal definition of equilibrium in app. A.2.

[15] In sec. VI, we study the quantitative performance of the more general formulation with $\pi \in [0, 1]$ in response to a temporary (persistent) shock to the nominal policy rate.

[16] For the general case with $\pi \in [0, 1]$, the marginal valuation ε_t^* would be defined as $\varepsilon_t^* \equiv (p_t \phi_t^m - \pi(1 - \delta)\phi_t^s)/z$, since for an investor with valuation ε, $\varepsilon z + \pi(1 - \delta)\phi_t^s$ is the payoff from keeping a share, and $p_t \phi_t^m$ is the payoff from selling the share for cash.

i) The equity price is $\phi_t^s = \phi^s = \beta(\bar{\varepsilon} + \mathcal{L})z$, with $\mathcal{L} \equiv \alpha\theta\int_{\varepsilon_L}^{\varepsilon^*}(\varepsilon^* - \varepsilon)\, dG(\varepsilon)$, where $\varepsilon^* \in (\varepsilon_L, \varepsilon_H)$ is the unique solution to $\alpha\theta\int_{\varepsilon^*}^{\varepsilon_H}(\varepsilon - \varepsilon^*/\varepsilon^*)\, dG(\varepsilon) = r$.

ii) Let (x^*, s_{+1}^*) denote the optimal investment and equity issuance for an entrepreneur with initial endowment $\omega \equiv w/k$. Then, if $\delta - \iota_0 \leq 1 \leq \phi^s$, we have

a) If $\phi_e^s \leq \phi^s$, then $x^* = \iota_s k$ and $s_{+1}^* = (1 - \delta)k + x^*$.

b) If $\phi^s < \phi_e^s$, then

$$\left(\frac{x^*}{k}, \frac{s_{+1}^*}{k}\right) = \begin{cases} (\iota_e, 0) & \text{if } \mathrm{c}(\iota_e) \leq \omega \\ (\mathrm{c}^{-1}(\omega), 0) & \text{if } \mathrm{c}(\iota_s) < \omega < \mathrm{c}(\iota_e) \\ \left(\iota_s, \dfrac{\mathrm{c}(\iota_s) - \omega}{\phi^s}\right) & \text{if } \omega \leq \mathrm{c}(\iota_s). \end{cases}$$

The first part of proposition 1 characterizes the equilibrium real stock price, ϕ^s, which is composed of the fundamental dividend value, $\bar{\varepsilon}z$, and the liquidity value, $\mathcal{L}z$, associated with the investor's first-subperiod retrading option. A higher nominal policy rate, r, reduces this liquidity value (because it reduces the real purchasing power of potential high-valuation buyers of the stock), which in turn reduces the stock price.[17] The magnitude of the equity price response to changes in the policy rate is increasing in the liquidity of the stock, that is, as measured by the parameter α, which determines the frequency of trade (or turnover) of the stock.[18]

The second part of proposition 1 characterizes the entrepreneur's optimal investment and capital structure decisions as functions of the equilibrium stock price characterized in the first part. Part *a* focuses on the case in which the market valuation of the marginal capital investment is higher than the entrepreneur's. In this case, the entrepreneur chooses the investment rate, ι_s, so that the marginal cost of investing equals the market value of the marginal investment. Moreover, because the entrepreneur's valuation is lower than the market valuation, the entrepreneur issues equity shares on any capital she owns at the beginning of the period and finances new investment entirely by equity issuance.[19] Part *b*

[17] Lagos and Zhang (2020) explain the mechanism in detail. Intuitively, an increase in the policy rate represents an increase in the opportunity cost of holding the monetary asset used to settle the equity trades in the first subperiod. And the marginal valuation ε^* is lower under the higher opportunity cost, reflecting the fact that the investor who was indifferent between holding money and equity under the lower policy rate prefers tilting her portfolio toward equity under the higher policy rate.

[18] This result is formalized in part vi of corollary 5 (app. A.6.2), which is analogous to part iii of prop. 6 in Lagos and Zhang (2020).

[19] In the knife-edge case with $\phi_e^s = \phi^s$, the entrepreneur is indifferent between financing by equity issuance or out of her own funds, ωk.

focuses on the case in which the entrepreneur's valuation of the marginal capital investment is higher than the market valuation, that is, $\phi^s < \phi_e^s$. In this case, the investment, financing, and consumption decisions of the entrepreneur depend on her own valuation of investment, on the market valuation, and on the entrepreneur's financial wealth, represented by the ω endowment of good 2. First, if $\mathrm{c}(\iota_e) \leq \omega$, the entrepreneur is financially unconstrained: she chooses her first-best investment rate, ι_e, finances it entirely with her own funds—that is, $s_{+1}^* = 0$ (issues no equity)—and consumes the unspent wealth, $\omega - \mathrm{c}(\iota_e)$. On the opposite extreme, if the entrepreneur's own financial wealth is very low, specifically $\omega \leq \mathrm{c}(\iota_s)$—that is, 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, ϕ^s—then she chooses the investment rate ι_s, uses all of her own funds to finance part of the investment, and resorts to equity issuance to finance the rest. Finally, if the entrepreneur's financial wealth is too low to self-finance her first-best investment rate but high enough to self-finance the investment rate that would be chosen based on outside investor's valuations—that is, if $\mathrm{c}(\iota_s) < \omega < \mathrm{c}(\iota_e)$—then the entrepreneur invests the maximum that can be financed with all her internal funds—that is, the investment rate ι^* that satisfies $\mathrm{c}(\iota^*) = \omega$—and issues no equity.

III. Implications of the Theory

The model presented in section II consists of two sectors: a financial sector (described in the first part of prop. 1) that determines the firm's equity price as a function of monetary policy, and an investment sector (described in the second part of prop. 1) that determines the firm's investment and capital structure as a function of the market price of its equity.[20] In the theory, monetary policy affects the real equity price only through what Lagos and Zhang (2020) labeled the "turnover-liquidity transmission mechanism," which we will refer to as the "turnover channel," for brevity.[21] The financial sector of our theory implies a pricing function, $\phi^s = \phi(r; \mathcal{T})$ (where $\mathcal{T}$ denotes the stock turnover) that satisfies $\partial\phi^s/\partial r < 0$ and $\partial^2\phi^s/(\partial r \partial \mathcal{T}) < 0$, which is all we need to motivate the relevance and exclusion restrictions in our empirical identification strategy.

[20] Specifically, the financial sector determines the firm's equity price as a function of (*a*) firm parameters (e.g., productivity, z), (*b*) financial investors' parameters (e.g., the distribution of idiosyncratic valuations, G), (*c*) the financial market structure where the firm's equity trades (the parameters α and θ), and (*d*) monetary policy (the parameter r).

[21] Lagos and Zhang (2020) use the longer terminology to emphasize the fact that the strength of this transmission mechanism depends on the market structure parameter α—a key determinant of the equity turnover rate, which is a standard measure of financial liquidity.

From the investment sector, we have learned that the investment and equity issuance decisions of firms with certain characteristics (e.g., low ω) respond to market-driven variations in their equity prices.[22] The q-channel is the theoretical mechanism that transmits financial market–driven changes in a firm's equity price to its investment and equity issuance decisions.

In the remainder of this section, we discuss the key implications of the theory that will guide the empirical analysis that we conduct in section IV. Section III.A explains the causal relationship that runs from Tobin's q to a firm's choices of investment and equity issuance, which we call the q-channel. Section III.B reviews the causal relationship that runs from the interaction between monetary policy and financial market turnover to a firm's equity price, which we call the turnover channel. In section III.C, we propose a theory-based empirical identification strategy for the q-channel that relies on the observation that the turnover channel implies the turnover of a firm's stock systematically affects the responsiveness of the stock price to money shocks.

A. *Tobin's* q, *Investment, and Capital Structure: The* q-*Channel*

The following corollary of proposition 1 establishes the conditions under which the marginal value of capital that the entrepreneur uses to make the optimal investment decision—which here we denote q^*—is equal to Tobin's q, which in this model equals the stock market price of a claim to the dividends from a unit of capital installed in the firm (i.e., ϕ^s).

Corollary 1. In equilibrium, the entrepreneur always chooses an investment rate, ι^*, that satisfies $c'(\iota^*) = q^*$, with $q^* = \phi^s$ if $\phi^s_e \le \phi^s$, or with

$$q^* = \begin{cases} \phi^s_e & \text{if } c(\iota_e) \le \omega \\ c'(c^{-1}(\omega)) & \text{if } c(\iota_s) < \omega < c(\iota_e) \\ \phi^s & \text{if } \omega \le c(\iota_s) \end{cases}$$

if $\phi^s < \phi^s_e$.

In a well-known proposition, Hayashi (1982) showed that for a competitive firm with constant returns to scale in both production and installation, the marginal value of capital that the firm uses to make the optimal investment decision, which Hayashi labeled "marginal q," is equal to the

[22] By "market-driven variations," we mean changes in the equity price that are not driven by changes in firm-level parameters. In our theory, market-driven variations may be due to changes in investor-level parameters, market structure parameters, or policy parameters.

ratio of the market value of the installed capital to the replacement cost of capital, that is, equal to Tobin's q, which Hayashi labeled "average q." Corollary 1 is a version of this proposition for our model, which differs from Hayashi's more traditional neoclassical model in two ways. First, we allow for heterogeneous valuations of the fundamental marginal revenue of capital installed inside the firm: these valuations may differ across investors as well as between investors and the entrepreneur who runs the firm. Second, firms in our model face financing constraints, which sometimes affect investment decisions.

In corollary 1, we define q^* as the marginal value of capital that the entrepreneur uses to make the firm's optimal investment decision, so the optimal investment rate, ι^*, always satisfies $\mathrm{c}'(\iota^*) = q^*$. Thus, q^* corresponds to what Hayashi refers to as marginal q in his neoclassical interpretation of Keynes and Tobin (e.g., Keynes 1936/1973; Tobin 1969). In our model, the market price of k units of capital installed in a firm is $\phi^s k$ (expressed in terms of good 2), and the replacement cost of k units of capital is k (also in terms of good 2), so Tobin's q (what Hayashi refers to as average q) is equal to ϕ^s.

The main takeaway from corollary 1 that will guide our empirical analysis in section IV is that, unless $\phi^s < \phi^s_e$ and $\mathrm{c}(\iota_s) < \omega$, the firm's investment and equity issuance decisions depend on the market price of equity (i.e., on Tobin's q). For firms run by entrepreneurs whose valuation of marginal investment is lower than the market valuation, as in part ii*a* of proposition 1, the relationship is simple: regardless of the firm's balance sheet, a higher stock price induces the firm to increase the investment rate and finance it with equity issuance. For firms run by entrepreneurs whose valuation of marginal investment is higher than the market valuation, as in part ii*b* of proposition 1, the relationship is more nuanced. On the one hand, investment and equity issuance are increasing in the equity price for firms run by entrepreneurs who are sufficiently financially constrained, in the sense that $\omega \leq \mathrm{c}(\iota_s)$. On the other hand, investment and equity issuance decisions do not respond to market-driven variation in Tobin's q for firms run by entrepreneurs who are financially unconstrained, in the sense that $\mathrm{c}(\iota_s) < \omega$.

To summarize, according to the theory, firms can be classified as equity dependent or as not equity dependent. The latter are firms that do not rely on equity issuance to finance investment (in prop. 1, these are the firms with $\phi^s < \phi^s_e$ and $\mathrm{c}(\iota_s) < \omega$ that finance all their investment with internal funds). The equity-dependent firms are firms that finance at least some of their investment by issuing equity in the open market, and therefore their equity issuance and investment decisions are influenced by changes in Tobin's q (in prop. 1, these are the firms with $\phi^s_e < \phi^s$, or $\phi^s < \phi^s_e$ and $\omega \leq \mathrm{c}(\iota_s)$). In the empirical analysis of section IV, we will interpret the data through the lens of a theoretical equilibrium with

$\phi^s < \phi^s_e$.[23] Accordingly, we will use a firm's liquidity ratio (defined as the proportion of liquid assets relative to total assets) as the empirical counterpart of ω, and will interpret a relatively low liquidity ratio as an indicator that the firm is equity dependent.[24]

B. *Monetary Policy, Market Liquidity, and Tobin's* q*: The Turnover Channel*

The first part of proposition 1 shows the equilibrium equity price is a function of the policy rate, r, and the market structure parameters, $\eta \equiv \alpha\theta$. In corollary 5 (app. A.6.2; apps. A–D are available online), we show that $\partial \log \phi^s / \partial r < 0$, that is, that the log of Tobin's q is decreasing in the policy rate. We also show that $\partial^2 \log \phi^s / \partial\eta\partial r < 0$, that is, that the marginal effect of the policy rate on the log of Tobin's q is stronger for equity shares that have a higher turnover rate (higher η).[25] This theoretical prediction is the hallmark of the turnover channel and will be the basis for our empirical identification strategy.[26]

[23] In app. B, we incorporate a simple agency problem between entrepreneurs and investors to show that, in order to have an equilibrium with $\phi^s < \phi^s_e$, one need not assume parameterizations where the fundamental value of the investment is higher for entrepreneurs than for outside investors, since the agency problem makes outside equity a relatively more costly source of financing than inside equity, as proposed by the so-called pecking-order theory (e.g., Myers and Majluf 1984).

[24] Notice that according to the theory, this simple operational definition of "equity dependence" based exclusively on ω can be too restrictive, as it may misclassify some equity-dependent firms as not equity dependent (e.g., firms with relatively high ω but $\phi^s_e = \phi^s$). In the data, however, we will find that firms with relatively high liquidity ratios tend to behave on average as not-equity-dependent firms, while firms with low liquidity ratios tend to behave on average as equity-dependent firms. Through the lens of the theory, this observation can be rationalized by an equilibrium with $\phi^s < \phi^s_e$—because all firms would behave as equity dependent in an equilibrium with $\phi^s_e < \phi^s$ (even those with very high values of ω), which is counterfactual.

[25] When we take the model to the data, we associate variation in η in the theory with empirical cross-stock variation in the turnover rate, $\mathcal{T}$. The turnover rate of a stock is defined as the ratio between the number of outstanding shares that are traded in a given time period and the total number of outstanding shares. From lemma 1 (app. A.3), we know that all financial investors with $\varepsilon < \varepsilon^*$ who have a trading opportunity in the first subperiod sell all their equity holding, so the turnover rate for a firm's stock is $\mathcal{T} = \alpha G(\varepsilon^*)$, which is strictly increasing in α (and in θ). Hence, the theory implies a monotonic relationship between η and $\mathcal{T}$. In a model similar to our financial sector, Lagos and Zhang (2020) show that cross-stock variation in $\mathcal{T}$ induced by cross-stock variation in G would have similar implications for the cross-sectional variation in stock prices and stock turnover as cross-stock variation in α.

[26] Lagos and Zhang (2020) document that this theoretical prediction holds at high frequency (daily) for various sortings of stocks into turnover classes. In sec. IV, we reconfirm that it holds at quarterly frequency and for a different sorting of stocks. For an intuitive understanding of this result, recall that the policy rate affects only the equity price by reducing the expected value of the resale option, i.e., $\mathcal{L}$ in the first part of prop. 1. So if η is close to zero, the value of the expected resale option is small, and the equity price barely responds to changes in the policy rate. Conversely, a higher probability of retrading (α) and a higher share of the gain from retrading (θ) make this transmission channel stronger.

C. Identification

In the theory of section II, monetary policy affects investment and capital structure only through its effect on the stock prices of equity-dependent firms. Thus, with data generated by the model, we could identify the q-channel of monetary transmission (i.e., the causal effect of monetary policy–induced changes in Tobin's q on the outcome variable) simply by regressing changes in the outcome variable on the changes in Tobin's q induced by monetary policy shocks. However, this way of estimating the q-channel with actual data is problematic because we cannot rule out the possibility that monetary policy shocks operate through other transmission variables that may affect both the outcome variable and Tobin's q concurrently. Next, we formalize this identification problem and propose a strategy to address it.[27]

For firm i in period t, let Y_t^i denote the outcome variable of interest (e.g., the firm's investment rate, or its equity issuance), which may be affected by D transmission variables, $\boldsymbol{v}_t^i \equiv (v_{1t}^i, \ldots, v_{Dt}^i) \in \mathbb{R}^D$. To make this dependence explicit, write the outcome variable as a function of the transmission variables, that is, $Y_t^i = Y(\boldsymbol{v}_t^i)$. In our application, the first transmission variable, $v_{1t}^i \equiv \mathrm{q}_t^i$, will be a measure of firm i's Tobin's q.[28] In turn, each transmission variable $j \in \{1, \ldots, D\}$ is a function of the policy rate r_t and a vector of N predetermined firm-level characteristics, $\boldsymbol{\kappa}^i \equiv (\kappa_1^i, \ldots, \kappa_N^i) \in \mathbb{R}^N$, that is, $v_{jt}^i = v_j(r_t, \boldsymbol{\kappa}^i)$. In our application, the first characteristic, $\kappa_1^i \equiv \mathcal{T}^i$, represents the turnover rate of firm i's stock.[29]

Suppose that from period $t-1$ to period t, the policy rate changes from r_{t-1} to $r_t = r_{t-1} + \varepsilon_t^m$, where ε_t^m represents an unexpected policy shock. First-order approximations to the function $v_j(\cdot)$ around the point $(\bar{r}, \bar{\boldsymbol{\kappa}}) \in \mathbb{R}^{N+1}$ (we use $\bar{\mathcal{T}}$ to denote $\bar{\kappa}_1$) and to the function $Y(\cdot)$ around the point $\bar{v} \equiv \boldsymbol{v}(\bar{r}, \bar{\boldsymbol{\kappa}}) \in \mathbb{R}^D$ imply

$$Y_t^i - Y_{t-1}^i \approx \gamma^{\mathrm{q}}(\mathrm{q}_t^i - \mathrm{q}_{t-1}^i) + u_t^i, \tag{8}$$

where $u_t^i \equiv \sum_{j=2}^D y^j(v_{jt}^i - v_{jt-1}^i) = \sum_{j=2}^D y^j \alpha_r^j \varepsilon_t^m$, with $\gamma^j \equiv \partial Y(\bar{\boldsymbol{v}})/\partial v_j$, $\alpha_r^j \equiv \partial v_j(\bar{r}, \bar{\boldsymbol{\kappa}})/\partial r$ for $j \in \{1, \ldots, D\}$, and $\gamma^1 \equiv \gamma^{\mathrm{q}}$. Intuitively, the coefficient α_r^j quantifies the first-order effect of a marginal increase in the policy rate on transmission variable j, and γ^j quantifies the first-order effect of a marginal increase in transmission variable j on the outcome variable. Since

[27] See app. C for more detailed derivations and proofs.

[28] Other elements of $\boldsymbol{v}_t^i$ could represent other firm-specific transmission variables, such as firm i's borrowing cost, user cost of capital, or the demand for its output, as well as market-wide transmission variables, e.g., a baseline real interest rate or other macro variables relevant for the firm's investment or capital structure decisions.

[29] Other elements of $\boldsymbol{\kappa}^i$ could be financial variables, e.g., leverage, or the proportion of liquid assets relative to total assets in the firm's balance sheet, or nonfinancial variables such as firm i's sector, size, or age.

we are interested in estimating γ^{q}, a natural empirical strategy suggested by the specification (8) would be to use the money shock, ε_t^m, as an instrument for $\mathrm{q}_t^i - \mathrm{q}_{t-1}^i$ to identify the policy-driven variation in the stock price. Our concern with this approach, however, is that it would be difficult to argue that the instrument ε_t^m satisfies the exclusion restriction, that is, that there is no correlation between the money shock, ε_t^m, and the residual, u_t^i. Notice that since $\mathrm{cov}(\varepsilon_t^m, u_t^i) = \mathrm{var}(\varepsilon_t^m)\Sigma_{j=2}^{D}\gamma^j\alpha_r^j$, we have $\mathrm{cov}(\varepsilon_t^m, u_t^i) = 0$ if and only if $\gamma^j\alpha_r^j = 0$ for all $j \in \{2, \ldots, D\}$. That is to say, the exclusion restriction is satisfied as long as the monetary shock has no effect on the outcome variable through transmission variables other than Tobin's q. In other words, the identifying assumption is that for all transmission variables $j \in \{2, \ldots, D\}$, either the money shock has no effect on transmission variable j (i.e., $\alpha_r^j = 0$) or transmission variable j has no effect on the outcome variable (i.e., $\gamma^j = 0$). The existing literature on monetary transmission discusses many conventional channels that violate this identifying assumption.[30]

We meet this identification challenge by exploiting the cross-sectional variation in the responsiveness of stock prices to monetary shocks that is associated with cross-sectional variation in stock turnover, which we refer to as the turnover channel. Specifically, we will regress changes in the outcome variable on changes in stock prices induced by monetary policy shocks, but our identification strategy will consist of using $\varepsilon_{it}^{\mathcal{T}m} \equiv (\mathcal{T}^i - \bar{\mathcal{T}})\varepsilon_t^m$ (i.e., the product between a firm-specific predetermined measure of stock turnover and the money shock) as an instrument for the change in the firm's stock price. Stock turnover has a strong effect on the pass-through of the policy shock to the stock price, which implies a strong correlation between the proposed instrument and the change in the stock price. This is the turnover-liquidity channel documented by Lagos and Zhang (2020). Our main insight is that the relevant exclusion restriction will be satisfied as long as an individual firm's stock turnover (and any unobserved firm-level characteristic that is correlated with stock turnover) has no effect on the responsiveness to the monetary policy shock of transmission variables other than Tobin's q that influence the outcome variable. This identifying assumption is weaker than the one needed for ε_t^m to be a valid instrument in the context of (8), in the sense that—as we explain below—it is not violated by the traditional transmission channels discussed in the literature.

[30] To illustrate, suppose the outcome variable Y_t^i is a measure of firm i's investment. According to the interest rate channel, e.g., an unexpected decrease in the nominal policy rate that passes through to the real interest rate would directly decrease the user cost of capital, which increases investment (through a transmission variable other than the stock price), leading to positive correlation between ε_t^m and u_t^i.

To describe our identification strategy in more detail, we now use a second-order approximation to the function $v_j(\cdot)$ around the point $(\bar{r}, \bar{\boldsymbol{\kappa}}) \in \mathbb{R}^{N+1}$ for every transmission variable $j \in \{1, \ldots, D\}$, which implies

$$v_{jt}^i - v_{jt-1}^i \approx \mathrm{a}_t^j + \sum_{n=1}^{N} \alpha_{rn}^j (\kappa_n^i - \bar{\kappa}_n)\varepsilon_t^m, \tag{9}$$

where $\mathrm{a}_t^j \equiv \{\alpha_r^j + \alpha_{rr}^j[\varepsilon_t^m + 2(r_{t-1} - \bar{r})]\}\varepsilon_t^m$, $\alpha_{rr}^j \equiv (1/2)(\partial v_j(\bar{r}, \bar{\boldsymbol{\kappa}})/\partial r \partial r)$, and $\alpha_{rn}^j \equiv (\partial v_j(\bar{r}, \bar{\boldsymbol{\kappa}}))/(\partial \kappa_n \partial r)$ for $n \in \{1, \ldots, N\}$. Intuitively, the coefficient α_{rr}^j quantifies the second-order effect of a marginal increase in the policy rate on transmission variable j, and the coefficient α_{rn}^j quantifies the variation in the effect of a marginal increase in the policy rate on transmission variable j due to variation in firm-level characteristic n. We want to allow for the possibility that only the first M firm-level characteristics are observed, while the remaining characteristics are unobserved and possibly correlated with the observed characteristics. (We always treat stock turnover as an observed characteristic, so the integer M satisfies $1 \le M \le N$.) To this end, we express an unobserved characteristic $s \in \{M+1, \ldots, N\}$ as $\kappa_s^i \approx \bar{\kappa}_s + \sum_{n=1}^{M} \varkappa_{sn}(\kappa_n^i - \bar{\kappa}_n)$, where $\varkappa_{sn}$ represents the correlation between unobserved characteristic s and observed characteristic n. (Our convention is to denote $\varkappa_{s1}$ with $\varkappa_{s\mathcal{T}}$.) We can now write the policy-induced change in transmission variable j, that is, (9), in terms of the interaction between the money shock and observed firm-level characteristics, that is,

$$v_{jt}^i - v_{jt-1}^i \approx \mathrm{a}_t^j + \sum_{n=1}^{M} \hat{\alpha}_{rn}^j (\kappa_n^i - \bar{\kappa}_n)\varepsilon_t^m, \tag{10}$$

where $\hat{\alpha}_{rn}^j \equiv \alpha_{rn}^j + \sum_{s=M+1}^{N} \alpha_{rs}^j \varkappa_{sn}$, for $n \in \{1, \ldots, M\}$. Representation (10) and the first-order approximation to the function $Y(\cdot)$ around the point $\bar{\boldsymbol{v}} \equiv \boldsymbol{v}(\bar{r}, \bar{\boldsymbol{\kappa}}) \in \mathbb{R}$ imply the policy-induced change in the outcome variable can be written as

$$Y_t^i - Y_{t-1}^i \approx \mathrm{b}_t + \gamma^{\mathrm{q}}(\mathrm{q}_t^i - \mathrm{q}_{t-1}^i) + \sum_{n=2}^{M} \tilde{\delta}_{rn}^{\sim \mathrm{q}} (\kappa_n^i - \bar{\kappa}_n)\varepsilon_t^m + \epsilon_{it}, \tag{11}$$

where $\mathrm{b}_t \equiv \sum_{j=2}^{D} \gamma^j \mathrm{a}_t^j$, $\tilde{\delta}_{rn}^{\sim \mathrm{q}} \equiv \sum_{j=2}^{D} \gamma^j \hat{\alpha}_{rn}^j$ and $\epsilon_{it} \equiv \tilde{\delta}_{r\mathcal{T}}^{\sim \mathrm{q}} \varepsilon_{it}^{\mathcal{T}m}$ (with $\tilde{\delta}_{r\mathcal{T}}^{\sim \mathrm{q}} \equiv \tilde{\delta}_{r1}^{\sim \mathrm{q}}$).

Since we are interested in estimating γ^{q}, our empirical strategy based on specification (11) is to use the money shock interacted with firm i's stock turnover, that is, $\varepsilon_{it}^{\mathcal{T}m}$, as an instrument for $\mathrm{q}_t^i - \mathrm{q}_{t-1}^i$ to identify "exogenous" policy-driven variation in the stock price. Two conditions need to be satisfied for $\varepsilon_{it}^{\mathcal{T}m}$ to be a valid instrument for $\mathrm{q}_t^i - \mathrm{q}_{t-1}^i$ in order to estimate γ^{q} by using (11) as the basis for an instrumental variable (IV) regression. First, $\varepsilon_{it}^{\mathcal{T}m}$ must be correlated with the change in firm i's stock price, $\mathrm{q}_t^i - \mathrm{q}_{t-1}^i$. This correlation is negative and strong—it is the turnover-liquidity mechanism documented by Lagos and Zhang (2020). Second, $\varepsilon_{it}^{\mathcal{T}m}$ must affect the outcome variable, Y_t^i, in the structural form (11) only through the transmission variable $q_t^i - q_{t-1}^i$. In other words, the instrument $\varepsilon_{it}^{\mathcal{T}m}$ must be uncorrelated with ϵ_{it}. But notice that $\text{cov}(\varepsilon_{it}^{\mathcal{T}m}, \epsilon_{it}) = \tilde{\delta}_{r\mathcal{T}}^{\sim q}(\mathcal{T}^i - \bar{\mathcal{T}})^2\text{var}(\varepsilon_t^m)$, so the exclusion restriction for $\varepsilon_{it}^{\mathcal{T}m}$ to be a valid instrument for $q_t^i - q_{t-1}^i$ is satisfied if and only if $\tilde{\delta}_{r\mathcal{T}}^{\sim q} = 0$, which is equivalent to

$$\sum_{j=2}^{D}\gamma^j\left(\alpha_{r\mathcal{T}}^j + \sum_{s=M+1}^{N}\alpha_{rs}^j\varkappa_{s\mathcal{T}}\right) = 0. \tag{12}$$

Condition (12) says that $\varepsilon_{it}^{\mathcal{T}m}$ can serve as an instrument for Tobin's q if for every $j \in \{2, \dots, D\}$ (i.e., for every transmission variable other than Tobin's q), either $\gamma^j = 0$ or $\alpha_{r\mathcal{T}}^j = \alpha_{rs}^j\varkappa_{s\mathcal{T}} = 0$ for all $s \in \{M+1, \dots, N\}$.[31] That is to say, the exclusion restriction is satisfied as long as stock turnover (and any unobserved firm-level characteristic that is correlated with turnover) has no effect on the pass-through of the monetary policy shock to transmission variables other than Tobin's q that influence the outcome variable.[32] On theoretical grounds, this identifying assumption is weaker than the one needed for ε_t^m to be a valid instrument (as discussed in the context of [8]), in the sense that it is not violated by the traditional transmission channels discussed in the literature. For example, if transmission variable $j \in \{2, \dots, D\}$ is an aggregate variable common to all firms, that is, if $v_{jt}^i = v_{jt}$ for all i, then the response of v_{jt} to the money shock will not be affected by the predetermined firm-level characteristics of any given firm i, so in particular, $\alpha_{r\mathcal{T}}^j = \alpha_{rs}^j = 0$ for all $s \in \{M+1, \dots, N\}$, so the identifying assumption $\gamma^j\hat{\alpha}_{r\mathcal{T}}^j = 0$ is automatically satisfied for transmission variable j. Thus, our identification strategy is very powerful to exclude traditional channels that operate through aggregate transmission variables that are not firm specific.[33]

[31] The condition $\gamma^j = 0$ means that j does not operate as a transmission variable for the outcome of interest. The condition $\alpha_{r\mathcal{T}}^j = 0$ means that firm i's stock turnover does not influence the marginal effect of the policy rate on transmission variable j. The condition $\alpha_{rs}^j\varkappa_{s\mathcal{T}} = 0$ for all $s \in \{M+1, \dots, N\}$ means that every unobserved characteristic that is correlated with stock turnover has no influence on the marginal effect of the policy rate on transmission variable j.

[32] In this formulation, since r_t is the only source of variation in transmission variables, $\tilde{\delta}_{r\mathcal{T}}^{\sim q} = 0$ implies $\epsilon_{it} = 0$. In app. C, we consider a more general formulation that allows for additional random variation (across firms and over time) in transmission variables, as well as for random variation (across firms) in the mappings between unobserved and observed firm-level characteristics.

[33] The "textbook" version of the interest rate channel described in n. 30 is an example of a transmission mechanism that operates through aggregate transmission variables that are not firm specific. Modern contributions in this area, e.g., Jeenas (2019) and Ottonello and Winberry (2020), emphasize that a monetary policy shock that affects the interest rate common to all firms can affect firms differently depending on firm-specific characteristics (e.g., an individual firm's leverage or its share of liquid assets in total assets). In terms of the framework that we use to think about identification, the transmission mechanisms in these papers can be represented with a transmission variable j that is specific to firm i, i.e., v_{jt}^i,

While we are not aware of mainstream monetary transmission mechanisms that operate through firm-specific transmission variables whose responsiveness to monetary policy shocks depends on firm-level stock turnover, one could certainly contrive mechanisms mediated by firm-specific transmission variables (other than Tobin's *q*) whose responsiveness to money shocks depends on firm or stock characteristics that are correlated with stock turnover. Our previous analysis of the identification problem, however, suggests that including in the regression interaction terms between the monetary shock and empirical proxies for these characteristics mitigates these concerns about identification. For example, existing work on firm-level investment responses to monetary shocks emphasizes the explanatory power of characteristics such as firm age, size, leverage, liquid assets, and the cyclicality of firm-level demand.[34] As another example, one may be concerned about the correlations between turnover and other stock characteristics, such as exposure to conventional risk factors, or measures of investor disagreement or financial distress. In robustness analysis (app. D), we control for equity issuance and investment responsiveness explained by all of these firm- and stock-level characteristics.[35]

In appendix C.1, we show how our identification strategy generalizes to situations in which transmission variables affect the outcome variable (as before) and the outcome variable feeds back into transmission variables. The result is that in this case, a specification like (11) can identify the full effect of Tobin's *q* on the outcome variable. That is, the estimated coefficient on Tobin's *q* will capture not only the first-round effect of variation in Tobin's *q* on the outcome variable but also the indirect effects (second-, third-, fourth-round effects, etc.) associated with the variation in other transmission variables caused by the feedback from the change in the outcome variable originally triggered by the instrumented shock to Tobin's *q*.

IV. Empirics

In this section, we use the identification strategy described in section III.C to obtain an empirical estimate of the effect of exogenous variations in Tobin's *q* on firms' investment and equity issuance decisions.

which measures the relevant firm-specific cost of investing (e.g., a firm-specific real interest rate or a firm-specific shadow cost). In this context, our identifying assumption requires that the responsiveness of the relevant firm-specific cost of investment to monetary policy shocks does not depend on firm-specific stock turnover (or unobserved firm-level characteristics correlated with stock turnover).

[34] Examples of papers that consider these characteristics, respectively, are Gertler and Gilchrist (1994), Cloyne et al. (2018), Jeenas (2019), Anderson and Cesa-Bianchi (2020), and Durante, Ferrando, and Vermeulen (2020).

[35] Our baseline estimations (sec. IV) already include industry-time dummies that control for industry-specific responsiveness.

Section IV.A describes the data. In section IV.B, we document that the financial turnover of a firm's stock is a significant determinant of the heterogeneous cross-firm responses of the outcome variables of interest (Tobin's q, equity issuance, and investment) to monetary shocks.[36] In section IV.C, we estimate IV regressions based on the representation (11) (with $\mathcal{T}^i\varepsilon_t^m$ as the instrument for q_t^i and [10] as the basis for the first-stage regression). The coefficient of interest is γ^{q}, which quantifies the q-channel, that is, the effect of an exogenous increase in Tobin's q on the outcome variable of interest (either equity issuance or investment). Our empirical analysis uses local projections in the spirit of Jordà (2005) but in a panel setting.

A. Data

Our empirical work uses firm-level measures of Tobin's q, equity issuance, and investment, as well as financial market data on trade volume for individual firms' stocks and a proxy for unexpected changes in the monetary policy rate. Our sample covers the period 1990Q1–2016Q4 and consists of the Compustat universe of publicly listed nonfinancial firms incorporated in the United States.[37]

For each individual common stock in the Center for Research in Security Prices database, we construct the daily turnover rate as the ratio of daily trade volume (total number of shares traded) to the number of outstanding shares. We average the daily turnover rate to obtain a quarterly series for firm i in quarter t (denoted $\mathcal{T}_t^i$) and merge it with the quarterly firm-level data from Compustat.[38]

The key variables that we construct from Compustat are Tobin's q, (normalized) equity issuance, and investment rate. We let q_t^i denote Tobin's q for firm i in quarter t and define it as the book value of total assets (denoted $\bar{\mathrm{V}}_{At}^i$) plus the difference between the market value of common equity (denoted V_{Et}^i) and the book value of common equity (denoted $\bar{\mathrm{V}}_{Et}^i$), all scaled by the book value of total assets, that is, $q_t^i \equiv 1 + (\mathrm{V}_{Et}^i - \bar{\mathrm{V}}_{Et}^i)/\bar{\mathrm{V}}_{At}^i$.[39] Our measure of (net) equity issuance for firm i in quarter t

[36] Specifically, we estimate reduced-form OLS regressions based on the representations (180; for Tobin's q, to estimate $\hat{\alpha}_{rT}^{\mathrm{q}}$) and (183; for equity issuance and investment, to estimate $\tilde{\delta}_{rn}$, which equals $\gamma^{\mathrm{q}}\hat{\alpha}_{rn}^{\mathrm{q}}$ under our identifying assumptions). Our interest in the reduced-form OLS regression for Tobin's q is twofold: it revisits the results in Lagos and Zhang (2020; using quarterly rather than daily data), and it serves as the first-stage for our IV approach.

[37] Since our regression specifications include simple firm fixed effects in a dynamic panel setting, we only include firms that are in the dataset for at least 40 quarters. We discuss sample selection and other aspects of data construction in more detail in app. E.

[38] In app. E.3, we report some statistics on stock turnover and its relation to other firm-level characteristics.

[39] This is the definition of average q in Kaplan and Zingales (1997), except that as in Baker, Stein, and Wurgler (2003) and Cloyne et al. (2018), we do not subtract deferred taxes from

(denoted E_t^i) consists of all equity sales minus all equity purchases from Compustat. We normalize these quarterly net issuances by the total balance sheet size of firm i at the beginning of quarter t (i.e., $\bar{\mathrm{V}}_{At-1}^i$) and work with $\mathrm{e}_t^i \equiv \mathrm{E}_t^i/\bar{\mathrm{V}}_{At-1}^i$.[40] We define investment of firm i in quarter t (denoted I_t^i) as capital expenditures from Compustat and construct the corresponding investment rate by dividing this measure by Compustat's measure of property, plant, and equipment (net of depreciation, depletion, and amortization) at the beginning of the quarter (denoted K_t^i).[41] In line with the theory, our measure of equity dependence will be based on the liquidity ratio for each firm in each quarter, denoted ℓ_t^i, defined as the ratio of the firm's cash and short-term investments, denoted L_t^i, to the book value of total assets (both from Compustat), that is, $\ell_t^i \equiv L_t^i/\bar{\mathrm{V}}_{At}^i$.

In order to construct unexpected changes in the nominal policy rate, we use the tick-by-tick nominal interest rate implied by the 3-month fed funds futures contract with nearest maturity after each regular monetary policy announcement of the Federal Open Market Committee (FOMC) and follow the event-study methodology that consists of estimating the changes that occur in a 30-minute window around the time of the FOMC announcement.[42] The identification assumption is that in such a narrow window around the press release, futures rates are not affected by variables or news other than the FOMC announcement.[43] Since the firm-level data from Compustat is quarterly, we sum up the high-frequency changes in the federal funds futures rate by quarter to arrive at a quarterly series of monetary policy shocks for quarter t (denoted ε_t^m).[44] We interpret a positive value of ε_t^m as a contractionary monetary shock, that is, an unexpected policy-induced increase in the nominal interest rate.[45]

the numerator (due to many missing values in our data). We follow Eberly, Rebelo, and Vincent (2012) and use $\mathrm{q}_t^i \equiv \log q_t^i$ in our regressions. This specification provides a better fit given the skewness in the firm-level data, as discussed by Abel and Eberly (2002).

[40] We measure the "beginning of quarter t" values of firms' stock variables with the values reported in Compustat as of the end of quarter $t-1$.

[41] In robustness analysis, we have verified that the main results we report below are virtually unchanged if we measure investment as capital expenditures' net of sales of property, plant, and equipment or if we construct the measure of the capital stock based on the perpetual inventory method. See app. E for more details on the construction of the variables used in the estimations.

[42] See, e.g., Kuttner (2001) and Gürkaynak, Sack, and Swanson (2005).

[43] In app. D.2, we redo our main estimations with an alternative series for the monetary shock proposed by Jarociński and Karadi (2020).

[44] Here we are following the standard practice, e.g., as in Cochrane and Piazzesi (2002), Gertler and Karadi (2015), Jeenas (2019), Ottonello and Winberry (2020), and Wong (2021).

[45] To construct the various measures of ε_t^m, we use the dataset used by Jarociński and Karadi (2020), which is in turn based on an updated version of the dataset used by Gürkaynak, Sack, and Swanson (2005). Since ε_t^m is possibly a noisy measure of the true monetary shocks, it should be used as an instrument in IV regressions (see, e.g., Stock and Watson 2018). In our reduced-form specifications (sec. IV.B), we treat ε_t^m as if it were

B. *Evidence from Reduced-Form Regressions*

In this section, we estimate "reduced-form" ordinary least squares (OLS) regressions to learn whether the measures of Tobin's q, equity issuance, and investment of firms with different (predetermined) stock turnover exhibit significantly different responses to monetary shocks.[46]

We estimate local projection panel regressions of the following form:

$$y_{t+h}^i = f_h^i + d_{h,s,t+h} + \rho_h y_{t-1}^i + \Lambda_h Z_{t-1}^i + \beta_h \mathcal{T}_{t-1}^i + \gamma_h \mathcal{T}_{t-1}^i \varepsilon_t^m + u_{h,t+h}^i, \quad (13)$$

where $h = 0, 1, \ldots, H$ denotes the time horizon at which the effects are being estimated, and y_t^i is the outcome variable of interest for firm i in quarter t; that is, $y_t^i \in \{\mathrm{q}_t^i, \mathrm{e}_t^i, \mathrm{x}_t^i\}$, where $\mathrm{q}_t^i \equiv \log(q_t^i)$ (log of Tobin's q), $\mathrm{e}_t^i \equiv \mathrm{E}_t^i/\bar{\mathrm{V}}_{At-1}^i$ (normalized net equity issuance), and $\mathrm{x}_t^i \equiv \log(I_t^i/K_t^i)$ (log of the investment rate).[47] The regressors are a fixed effect for firm i at projection horizon h (denoted f_h^i); an industry-quarter dummy (2-digit SIC, quarter $t + h$) at projection horizon h (denoted $d_{h,s,t+h}$); the value of the outcome variable in the quarter prior to the shock (y_{t-1}^i); a vector of controls (denoted Z_{t-1}^i) that consists of firm i's size (measured by log total assets), leverage (measured by the ratio of total debt to total assets), and liquidity ratio, all measured in the quarter prior to the shock; the measure of the turnover rate of firm i's stock in the quarter prior to the shock ($\mathcal{T}_{t-1}^i$); and the interaction between this lagged turnover rate and the quarterly measure of the monetary policy shock discussed above (ε_t^m). The error term in the h-quarter-horizon projection of the outcome variable of period $t + h$ for firm i is denoted $u_{h,t+h}^i$. The coefficients to be estimated are ρ_h, Λ_h, β_h, and γ_h. We are interested in γ_h, which measures the effect of stock turnover on the responsiveness of the outcome variable to monetary shocks at horizon h.

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an accurate measure of the true monetary shocks. In our main empirical IV specifications (sec. IV.C), we instead use ε_t^m to construct an instrument for changes in stock prices.

[46] Our regression equations are based on the representations (180; for Tobin's q), and (183; for equity issuance and investment) derived in the appendix. The regressions involving Tobin's q are a robustness check of the empirical findings in Lagos and Zhang (2020), who document the effect of stock turnover on the sensitivity of stock prices to money shocks at a daily frequency (rather than quarterly, as we do here). The regressions involving investment quantify the relevance of the q-monetary transmission mechanism for the real economy. The regressions involving equity issuance test our theoretical prediction that firms respond to monetary policy–driven increases in their equity prices by issuing more equity (an instance of the "market timing" behavior studied by Baker and Wurgler 2002).

[47] We use the log of the investment rate since it will provide a better fit of the data given the skewness in the firm-level investment rates, as discussed by Abel and Eberly (2002). In app. D, we verify that our main empirical findings are robust to measuring the investment rate in levels. In app. A.6.3, we cast our theoretical results in terms of the model counterparts of the variables that we use in our empirical estimation, i.e., the log of the investment rate ($\log \iota^*$), the log of Tobin's q ($\log \phi^s$), and the value of equity issuance relative to the firm's assets ($\phi^s s_{+1}^*$).

The baseline specification (13) uses lagged stock turnover to ensure it is unaffected by ε_t^m and can therefore be regarded as a measure of the exposure of firm i's stock to the monetary shock.[48] As discussed in section III.C, our identification strategy relies on the cross-sectional variation in the responsiveness of the outcome variable to monetary policy shocks that is induced by cross-sectional variation in firm-level stock turnover. The industry-time dummy $d_{h,s,t+h}$ is a flexible way to isolate this cross-sectional variation, so that the estimate of γ_h is driven by within-industry, between-firm variation across time.

We divide the measure of turnover, $\mathcal{T}_t^i$, by the time-series average of the standard deviation of turnover in the cross-section of firms, and we divide the measure of the monetary shock, ε_t^m, by its standard deviation between 1990Q1–2016Q4 (approximately 9.66 basis points [bp]). We multiply the outcome variable y_t^i by 100, so the estimated coefficients (e.g., β_h, γ_h) associated with changes in e_t^i are interpreted in percentage points, while the estimated coefficients associated with changes in q_t^i or x_t^i correspond to percentage changes. Figure 1 reports the point estimates and 95% confidence intervals for γ_h for the three outcome variables of interest: the log of Tobin's q (i.e., q_t^i), normalized equity issuance (e_t^i), and the log investment rate (x_t^i).

Figure 1*A* shows that the turnover of a firm's stock significantly predicts the response of that firm's stock price to the money shock and that the effect persists for about 3 quarters. Since equity markets respond fast to shocks, the effects are strongest in the quarter of the monetary policy shock. The corresponding point estimate is approximately −0.5, which says that a firm whose stock turnover is 1 standard deviation higher than the average (across firms and over time) experiences a 0.5% stronger contraction in Tobin's q in response to a 1 standard deviation contractionary monetary policy shock.

Figure 1*B* shows that the turnover of a firm's stock negatively predicts the change in a firm's normalized equity issuance in response to a contractionary money shock. The estimate is statistically significant 2, 3, 4, 7, and 10 quarters after the shock. The estimated coefficient of approximately −0.06 at the 2-quarter horizon says that a firm whose stock turnover is 1 standard deviation higher than the average (across firms and over time) experiences a 0.06 percentage point larger decline in net equity issuance relative to book assets 2 quarters after a 1 standard deviation contractionary monetary shock.

[48] Given persistence in stock turnover from one quarter to the next, the turnover for quarter $t-1$ proxies for turnover immediately before the FOMC announcement in quarter t. For the same reason, we lag the additional firm-level control variables in the robustness analysis of app. D.

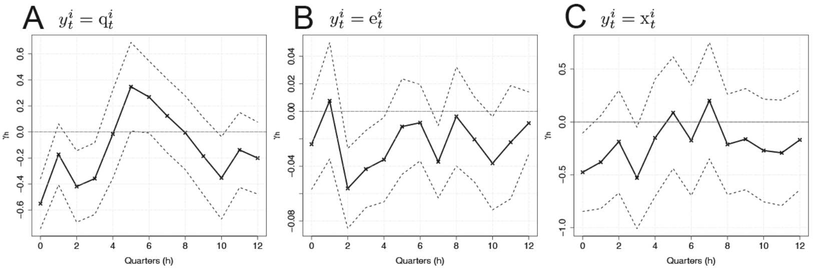

FIG. 1.—Effect of stock turnover on dynamic responses to monetary shocks (all firms). Point estimates and 95% confidence intervals for γ_h are from specification (13). Confidence intervals were constructed based on two-way clustered standard errors at firm and SIC 3-digit industry-quarter levels.

Figure 1*C* shows that the turnover of a firm's stock negatively predicts the change in a firm's investment rate in response to a contractionary money shock. The effect is statistically significant in the quarter of the shock and at the 3-quarter horizon. The estimated coefficient of approximately -0.5 in quarter 3 says that a firm whose stock turnover is 1 standard deviation higher than the average (across firms and over time) experiences a 0.5% larger decline in its investment rate 3 quarters after a 1 standard deviation contractionary monetary shock.

The specification (13) is informative, but it pools firms without distinguishing between their individual need for external financing. As discussed in section III.A, according to the theory, firms can be classified as equity dependent or as not equity dependent. The former have low liquid assets and finance at least part of their investment by issuing equity in the open market, and therefore their equity issuance and investment decisions are influenced by policy-induced changes in their stock prices. The latter have high liquid assets and do not rely on equity issuance to finance investment, so while their stock prices respond to monetary policy shocks, their equity issuance and investment decisions are insensitive to variation in stock prices induced by monetary policy shocks.

To test this theoretical prediction, we use the liquidity ratio, $\ell^i_t \equiv L^i_t/\bar{\mathrm{V}}^i_{At}$, as an indicator that the firm is equity dependent.[49] Specifically, 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, and estimate the following generalization of (13):

[49] We regard the liquidity ratio as the empirical counterpart of ω in the theory, since it measures the availability of a broad set of liquid assets that the firm can use to finance expenditures internally.

$$y_{t+h}^{i} = f_h^i + \tilde{f}_h^i \mathbb{I}_{L,t-1}^i + d_{h,s,t+h} + \tilde{d}_{h,s,t+h}\mathbb{I}_{L,t-1}^i + (\rho_h + \tilde{\rho}_h \mathbb{I}_{L,t-1}^i) y_{t-1}^i + (\Lambda_h + \tilde{\Lambda}_h \mathbb{I}_{L,t-1}^i) Z_{t-1}^i + (\beta_h + \tilde{\beta}_h \mathbb{I}_{L,t-1}^i)\mathcal{T}_{t-1}^i + (\gamma_h + \tilde{\gamma}_h \mathbb{I}_{L,t-1}^i)\mathcal{T}_{i,t-1}\varepsilon_t^m + u_{h,t+h}^i. \quad (14)$$

We are interested in estimating γ_h, which now measures the effect of stock turnover on the responsiveness of the outcome variable at horizon h to monetary shocks, for firms with a high liquidity ratio in the quarter prior to the shock. We are also interested in estimating $\gamma_h + \tilde{\gamma}_h$, which measures the effect of stock turnover on the responsiveness of the outcome variable at horizon h to monetary shocks, for firms with a low liquidity ratio in the quarter prior to the shock. Figure 2 reports the point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ for the three outcome variables of interest: the log of Tobin's q (i.e., q_t^i), normalized equity issuance (e_t^i), and the log investment rate (x_t^i).

Figure 2*A* shows that the financial turnover-liquidity channel documented in Lagos and Zhang (2020)—that is, the finding that the turnover of a firm's stock negatively predicts the change in a firm's stock price in response to a contractionary monetary policy shock—operates similarly across the stocks of firms with different preshock liquidity ratios. The estimated dynamic responses are close to those estimated on the pooled sample in specification (13). The effects are strongest in the quarter of the monetary policy shock (the point estimate for γ_0 is close to -0.5 and significant for both types of firms).

Figure 2*B* shows that, for firms with preshock liquidity ratios above the median, turnover does not in general predict a significant response of equity issuance to money shocks. On the other hand, conditional on belonging to the group with below-median liquidity ratios prior to the shock,

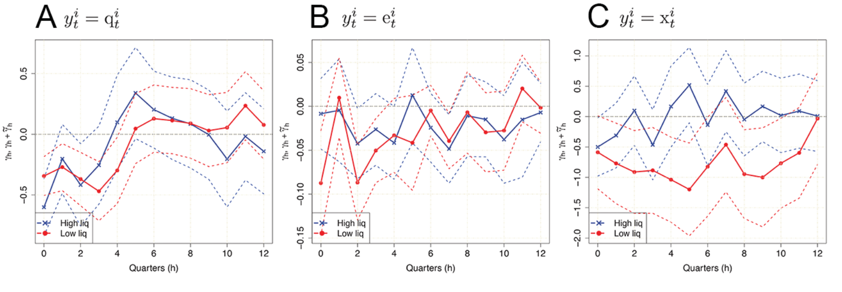

FIG. 2.—Effect of stock turnover on dynamic responses to monetary shocks (conditional on liquidity ratio). Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ are from specification (14). Confidence intervals were constructed based on two-way clustered standard errors at firm and SIC 3-digit industry-quarter levels.

firms with higher stock turnover exhibit significantly stronger contractions in equity issuance in response to a contractionary money shock in the quarter of the shock and also 2, 3, and 7 quarters after the shock. The point estimate of $\gamma_h + \tilde{\gamma}_h$ is roughly -0.08 on impact. This means that a firm with a preshock liquidity ratio below the median whose stock has a turnover rate that is 1 standard deviation above the average (across all firms and over time) experiences a 0.08 percentage point larger decline in net equity issuance relative to book assets in response to a 1 standard deviation contractionary monetary shock. Taken together, figures 1*B* and 2*B* indicate that the overall negative effect of turnover on the response of equity issuance to contractionary monetary policy shocks during the first 2 years is driven by firms with relatively low liquid asset holdings.

Figure 2*C* shows that for firms with preshock liquidity ratios above the median, turnover does not tend to have a significant effect on the response of the investment rate to money shocks. On the other hand, conditional on belonging to the group with below-median liquidity ratios prior to the shock, firms with higher stock turnover exhibit significantly stronger contractions in investment rates in response to a contractionary money shock up to 2 years after the shock. The point estimate of $\gamma_h + \tilde{\gamma}_h$ is about -1 at the 4-quarter horizon. This means that a firm with preshock liquidity ratio below the median whose stock has a turnover rate that is 1 standard deviation above the average (across all firms and over time) experiences a 1% larger decline in its investment rate 4 quarters after a 1 standard deviation contractionary monetary shock.

C. Evidence from IV Regressions

In this section, we use the identification strategy described in section III.C to estimate the effect of exogenous variation in Tobin's q on firms' equity issuance and investment. Instead of the reduced-form specification (13) for $y_t^i \in \{\mathrm{e}_t^i, \mathrm{x}_t^i\}$ that uses the interaction term $\mathcal{T}_{t-1}^i \varepsilon_t^m$ directly as a regressor, we now adopt an IV specification that uses as a regressor the measure of the firm's Tobin's q instrumented with the interaction term $\mathcal{T}_{t-1}^i \varepsilon_t^m$ (and uses [13] with $y_t^i = \mathrm{q}_t^i$ as the first stage of the IV procedure). Under the identification assumptions discussed in section III.C, we think of variation in q_t^i instrumented with $\mathcal{T}_{i,t-1}\varepsilon_t^m$ as the exogenous variation in (the log of) Tobin's q that is driven by monetary policy shocks. Our baseline IV specification is

$$y_{t+h}^i = f_h^i + d_{h,s,t+h} + \rho_h y_{t-1}^i + \Lambda_h Z_{t-1}^i + \beta_h \mathcal{T}_{t-1}^i + \gamma_h \mathrm{q}_t^i + u_{h,t+h}^i, \qquad (15)$$

where q_t^i is instrumented with $\mathcal{T}_{i,t-1}\varepsilon_t^m$, and Z_{t-1}^i is the same vector of controls used in (13). Figure 3 depicts the point estimates of γ_h and the corresponding 95% confidence intervals for $y_{t+h}^i \in \{\mathrm{e}_t^i, \mathrm{x}_t^i\}$.

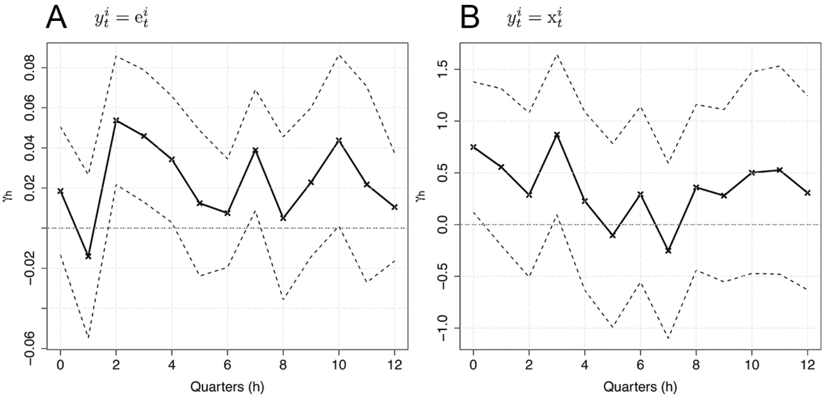

FIG. 3.—Dynamic responses of equity issuance and investment rate to instrumented changes in Tobin's q (all firms). Point estimates and 95% confidence intervals for γ_h are from estimating specification (15). Confidence intervals were constructed based on two-way clustered standard errors at firm and SIC 3-digit industry-quarter levels.

The IV estimates are in line with what one would expect based on the reduced-form OLS results reported in section IV.B.[50] Figure 3*A* shows that equity issuance responds positively to increases in Tobin's q instrumented with the turnover-liquidity mechanism (measured by the interaction term $\mathcal{T}_{t-1}^{i}\varepsilon_t^m$). The point estimate is statistically significant 2, 3, 4, 7 and 10 quarters after the shock. To get a sense of the magnitude of a response, the estimate 0.05 for $h = 2$ means that a 1% increase in a firm's measure of Tobin's q causes a 0.05 percentage point increase in the firm's ratio of net equity issuance relative to the book value of total assets 2 quarters after the monetary shock. Figure 3*B* shows that an increase in Tobin's q leads to an increase in the investment rate that is statistically significant in the quarter of the shock and 3 quarters after the shock. The point estimate at the 3-quarter horizon is about 0.8, which means that a 1% increase in a firm's Tobin's q leads to a 0.8% increase in the firm's investment rate.

The specification (15) is the IV counterpart of (13), in that it pools firms without conditioning on their need for external financing. As discussed above (e.g., in sec. III.A or in the discussion leading to [14]), according to the theory, policy-induced changes in Tobin's q should affect only the equity issuance and investment decisions of equity-dependent firms, which have relatively low liquidity ratios. Thus, next we use the liquidity indicator $\mathbb{I}_{L,t}^{i}$ introduced in (14) to proxy for equity dependence and estimate the following generalization of (15):

[50] The estimates in fig. 1*A* and 2*A* do not seem to suggest that $\mathcal{T}_{t-1}^{i}\varepsilon_t^m$ is a weak instrument for q_t^i in the cross-section of firms. In fact, e.g., when $y_t^i = x_t^i$, the first stage *F*-statistic on the instrument is 16.0 at horizon $h = 0$.

$$
\begin{aligned}
y^i_{t+h} = {} & f^i_h + \tilde{f}^i_h \mathbb{I}^i_{L,t-1} + d_{h,s,t+h} + \tilde{d}_{h,s,t+h}\mathbb{I}^i_{L,t-1} \\
& + (\rho_h + \tilde{\rho}_h \mathbb{I}^i_{L,t-1}) y^i_{t-1} + \left(\Lambda_h + \tilde{\Lambda}_h \mathbb{I}^i_{L,t-1}\right) Z^i_{t-1} \\
& + \left(\beta_h + \tilde{\beta}_h \mathbb{I}^i_{L,t-1}\right) \mathcal{T}^i_{t-1} + (\gamma_h + \tilde{\gamma}_h \mathbb{I}^i_{L,t-1}) \mathrm{q}^i_t + u^i_{h,t+h},
\end{aligned} \tag{16}
$$

where q^i_t and $\mathbb{I}^i_{L,t-1}\mathrm{q}^i_t$ are instrumented with $\mathcal{T}^i_{t-1}\varepsilon^m_t$ and $\mathbb{I}^i_{L,t-1}\mathcal{T}^i_{t-1}\varepsilon^m_t$, respectively, and Z^i_{t-1} is the same vector of controls used in (15). Figure 4 depicts the point estimates of γ_h and $\gamma_h + \tilde{\gamma}_h$ and the corresponding 95% confidence intervals for $y^i_t \in \{\mathrm{e}^i_t, \mathrm{x}^i_t\}$.

Figure 4*A* shows that for firms with below-median liquidity ratios, there is a positive statistically significant response of equity issuance to increases in Tobin's *q* in the quarter of the money shock (and in several subsequent quarters, e.g., in the second, third, and seventh quarters after the shock). For example, the estimated response on impact is approximately $\gamma_0 + \tilde{\gamma}_0 = 0.08$, which means that for a firm with a liquidity ratio below the median, a 1% increase in Tobin's *q* causes a 0.08 percentage point increase in the firm's ratio of net equity issuance relative to the book value of total assets in the quarter of the monetary shock. For firms with above-median liquidity ratios, the response is not significantly different from zero at any horizon.

Figure 4*B* shows that for firms with below-median liquidity ratios, there is a positive statistically significant response of the investment rate to increases in Tobin's *q* in the quarter of the money shock and in the following 6 quarters after the shock. For these firms, a 1% increase in

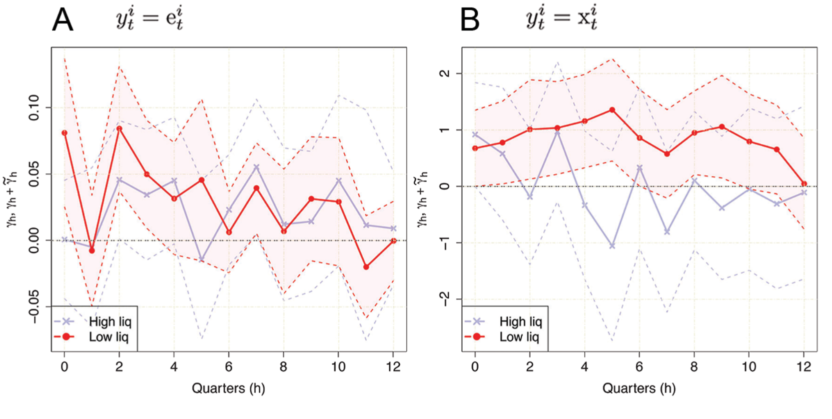

FIG. 4.—Dynamic responses of equity issuance and investment rate to instrumented changes in Tobin's *q* (conditional on liquidity ratio). Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ are from specification (16). Confidence intervals were constructed based on two-way clustered standard errors at firm and SIC 3-digit industry-quarter levels.

Tobin's q implies an elevated investment rate for up to 6 quarters after the shock, with a response of approximately 1% higher investment rate at the 2–6-quarter horizon. The investment rate of firms with liquidity ratios above the median exhibits no statistically significant responses, except marginally, at impact.

In appendix D, we verify that all our main findings are robust to controlling for an array of firm characteristics (age, size, leverage, liquidity ratio, and cyclicality of sales) and stock characteristics (return volatility and exposure to the three standard Fama and French 1993 factors).

D. Asset and Capital Structure Dynamics

In section IV.C, we documented that exogenous increases in Tobin's q (i.e., increases in stock prices associated with monetary policy–induced changes in turnover liquidity) stimulate the equity issuance and investment of firms with relatively low liquidity ratios. In this section, we broaden our focus and use the methodology of section IV.C to study the effect of Tobin's q on a firm's capital structure and composition of assets. Figure 5 shows the dynamic responses that result from estimating specification (16) using the main balance-sheet items as outcome variables.

Figure 5*A* shows the response of the book value of total assets, measured by $\log(\bar{V}^i_{At})$. Firms with below-median liquidity ratios respond to changes in Tobin's q by increasing their size, suggesting that the higher equity issuance documented in figure 4 does not immediately flow out of the firms. The estimate of about 0.25 at the 2-quarter horizon means that a 1% increase in Tobin's q leads to a 0.25% growth in the firm's total assets. The book value of total assets of firms with above-median liquidity ratios does not exhibit a statistically significant response to Tobin's q.

Figure 5*B* shows the response of the book value of total liabilities, measured as $\log(\bar{V}^i_{At} - \bar{V}^i_{\bar{E}t})$ (where $\bar{V}^i_{\bar{E}t}$ denotes the book value of all equity, i.e., common and preferred). For high-liquidity firms, the response is not significantly different from zero at any horizon. Low-liquidity firms seem to be increasing their total liabilities in response to changes in Tobin's q, although the magnitude of the response is smaller than the response of log assets, and it is only statistically different from zero at horizons longer than 10 quarters. These findings, together with the earlier finding that low-liquidity firms tend to increase their net equity issuances, imply that these firms make persistent changes to their capital structure in response to market-driven variations in Tobin's q. This result is evident from figure 5*C*, which shows the dynamic responses of the liabilities ratio, defined as the ratio of the book value of all liabilities to the book value of total assets, that is, $(\bar{V}^i_{At} - \bar{V}^i_{\bar{E}t})/\bar{V}^i_{At}$. The response of the liabilities ratio is significant and persistent for firms with below-median liquidity ratios. For example, at the 3-quarter horizon, the point

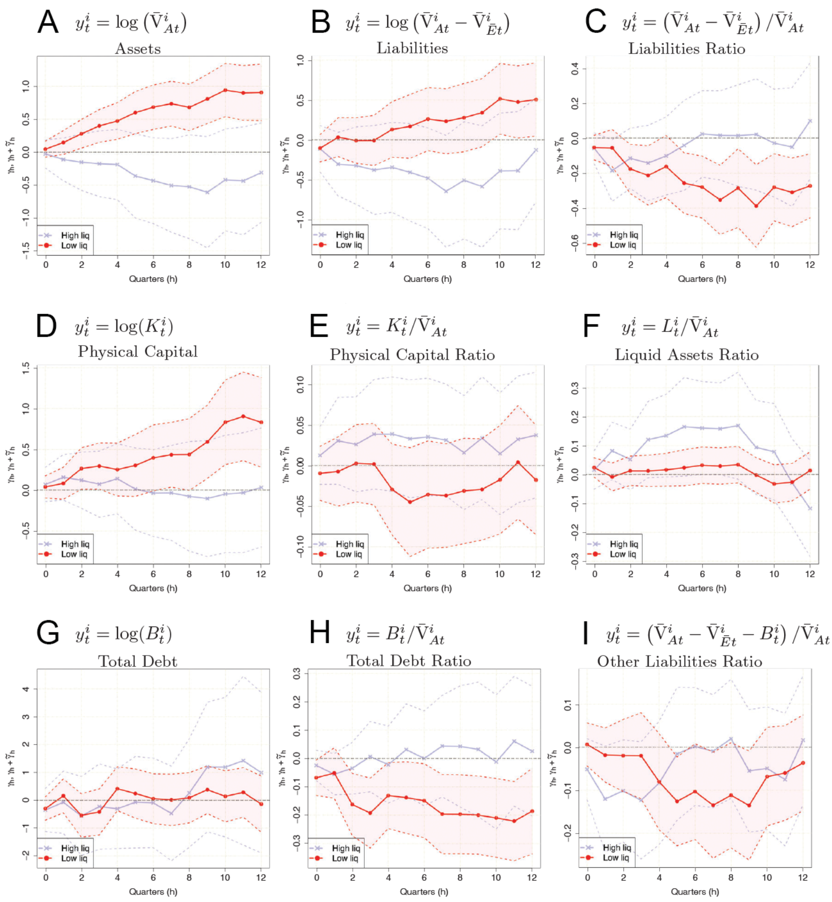

FIG. 5.—Effect of stock turnover on dynamic responses of capital structure to monetary shocks (conditional on liquidity ratio). Point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ are from specification (16). Confidence intervals were constructed based on two-way clustered standard errors at firm and SIC 3-digit industry-quarter levels.

estimate for $\gamma_h + \tilde{\gamma}_h$ is -0.2, which means that a shock that causes a 1% increase in Tobin's q leads to a 0.2 percentage point reduction in the liabilities ratio 3 quarters after the shock. In sum, firms with below-median liquidity ratios tilt their capital structure toward equity financing. The capital structure of firms with above-median liquidity ratios does not exhibit a statistically significant response to Tobin's q.

Panels *D–F* of figure 5 show the dynamic responses of a decomposition of firms' assets. Figure 5*D* shows the response of physical capital defined as $\log(K_t^i)$, where K_t^i denotes the book value of net property, plant, and equipment. The fact that the stock of physical capital rises significantly for low-liquidity firms (and does not respond for high-liquidity firms) lines up with the investment responses estimated in figure 4. Figure 5*E* shows the response of the physical capital ratio, defined as $K_t^i/\bar{V}_{At}^i$. Figure 5*F* shows the response of the liquid assets ratio, defined as $L_t^i/\bar{V}_{At}^i$, where L_t^i denotes the book value of cash and short-term investments. Taken together, panels *D*–*F* show no evidence of significant shifts in the relative sizes of the main asset classes. This suggests that the low-liquidity firms that respond to increases in their stock prices by issuing equity use the newly raised funds to scale up all their assets roughly in equal proportion. The asset structures of firms with above-median liquidity ratios do not exhibit statistically significant responses.

Panels *G*–*I* show the dynamic responses in the composition of firms' liabilities. Figure 5*G* shows the response of the log of total debt, denoted $\log(B_t^i)$. Figure 5*H* shows the response of the total debt ratio (i.e., leverage), defined as the ratio of the book value of total debt to the book value of total assets, that is, $B_t^i/\bar{V}_{At}^i$. Figure 5*I* shows the response of the other liabilities ratio, defined as the ratio of all liabilities other than debt to the book value of total assets, that is, $(\bar{V}_{At}^i - \bar{V}_{\bar{E}t}^i - B_t^i)/\bar{V}_{At}^i$. Figure 5*G* indicates that firms do not seem to engage in any active managing of their total debt in response to changes in Tobin's *q*. Figure 5*H* shows a persistent decrease in the total debt ratio of low-liquidity firms (i.e., a decrease in leverage), consistent with the responses in panels *A* and *G*. Finally, Figure 5*I* shows that the persistent decline in the liabilities ratio for low-liquidity firms documented in panel *C* is mostly accounted for by the persistent decline in the total debt ratio.

V. *q*-Channel and Monetary Transmission: Macro Implications

In this section, we quantify the relevance of the *q*-channel in the transmission of monetary shocks to aggregate investment. We do this in two ways. First, we report the cross-sectional distribution of estimates for the semielasticity of investment to money shocks transmitted through the *q*-channel.[51] Second, we use our microlevel estimates to produce an estimate of the semielasticity of aggregate investment to money shocks transmitted through the *q*-channel.

According to specification (16), the semielasticity of the investment rate of firm i in quarter $t + h$ to a monetary shock in quarter t is

[51] The responses across these firms are heterogeneous because their stocks have different turnover, which leads to heterogeneous stock price responses to the same money shocks (due to the turnover-liquidity channel) and because their liquidity ratios are classified as either high or low, which leads to heterogeneous investment responses to the same variation in Tobin's *q*.

$$\frac{d\log(I^i_{t+h}/K^i_{t+h})}{d\varepsilon^m_t} = \frac{d\log(I^i_{t+h}/K^i_{t+h})}{d\log(q^i_t)}\frac{d\log(q^i_t)}{d\varepsilon^m_t} \\ = (\gamma_h + \tilde{\gamma}_h\mathbb{I}^i_{L,t-1})\frac{d\log(q^i_t)}{d\varepsilon^m_t}, \tag{17}$$

where I^i_t, K^i_t, and q^i_t denote firm i's investment, capital stock, and Tobin's q in quarter t, respectively (all as defined in sec. IV.A); ε^m_t denotes the monetary policy shock in quarter t (expressed as a multiple of the standard deviation of monetary shocks in the sample, as in sec. IV); and $\mathbb{I}^i_{L,t}$ is an indicator that equals 1 if firm i has a liquidity ratio below the median and 0 otherwise. The estimates of γ_h and $\tilde{\gamma}_h$ are reported in figure 4*B*. To obtain estimates for $d\log(q^i_t)/d\varepsilon^m_t$, we estimate the following regression:

$$\log(q^i_t) = f^i + \beta_0\log(q^i_{t-1}) + \beta_1\mathcal{T}^i_{t-1} + \beta_2\varepsilon^m_t + \beta_3\mathcal{T}^i_{t-1}\varepsilon^m_t + u^i_t, \tag{18}$$

where f^i is a stock fixed effect, and u^i_t is the error term for stock i in quarter t.[52] With (18), (17) can be written as

$$\frac{d\log(I^i_{t+h}/K^i_{t+h})}{d\varepsilon^m_t} = (\gamma_h + \tilde{\gamma}_h\mathbb{I}^i_{L,t-1})(\beta_2 + \beta_3\mathcal{T}^i_{t-1}). \tag{19}$$

Figure 6 shows the cross-sectional distribution (across all firms and quarters) of the semielasticities of the investment rate to the money shock at the 4-quarter horizon, that is $\{d\log(I^i_{t+4}/K^i_{t+4})/d\varepsilon^m_t\}_{i,t}$, across firms i and quarters t in our sample.

Next, we assess the quantitative relevance of the q-channel for aggregate investment, $\bar{I}_t = \Sigma_{i\in\mathbb{F}}I^i_t$, where I^i_t is the level of investment of firm i in quarter t, and $\mathbb{F}$ denotes the set of firms in our sample.[53] We are interested in using the distribution of firm-level estimates of the semielasticity of the investment rate to money shocks, $d\log(I^i_{t+h}/K^i_{t+h})/d\varepsilon^m_t$ (from [17]) to obtain an estimate of the aggregate semielasticity of investment to money

[52] This specification is similar to (20) in Lagos and Zhang (2020), which is one of the specifications they use to estimate the turnover-liquidity channel but at a daily frequency. The estimated coefficients of interest are $\beta_2 = -0.385408$ and $\beta_3 = -0.098106$. The first estimate means that the direct (first-order) effect of a 1 standard deviation surprise increase in the policy rate is to reduce a firm's stock price by about -0.39% in the quarter when the shock occurred. (Since the standard deviation of ε_t is 9.66 bp in our sample, this estimate implies a 101 bp decline in the stock price in response to a 25 bp surprise increase in the fed funds rate.) The second estimate means that a firm whose stock turnover is 1 standard deviation higher than the average (across firms and over time) experiences a 0.1% stronger contraction in Tobin's q in response to a 1 standard deviation contractionary monetary policy shock.

[53] We will also provide estimates for the case where $\mathbb{F}$ is the set of all firms, not just publicly traded firms.

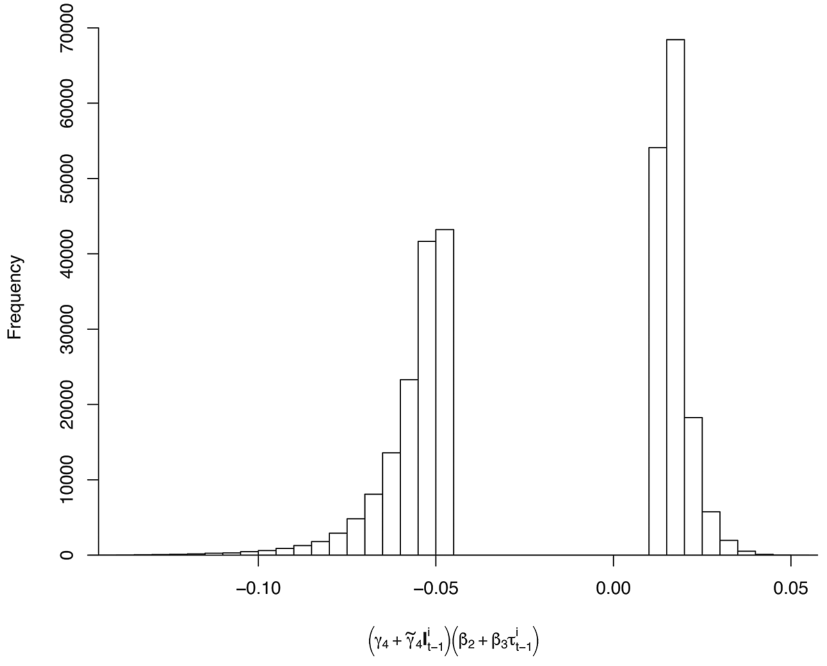

Fig. 6.—Distribution (across all firms and quarters) of semielasticity of investment rate at horizon $h = 4$ to a 1 bp surprise in the fed funds rate (computed as in the right side of [19]).

shocks, that is, $d\log(\bar{I}_{t+h})/d\varepsilon_t^m$. If, as is typically the case empirically, we have $d\log(I^i_{t+h-s})/d\varepsilon_t^m \leq 0$ for $s \in \{1, \ldots, h\}$ and $i \in \mathbb{F}$, then

$$\frac{d\log(\bar{I}_{t+h})}{d\varepsilon_t^m} \leq \sum_{i\in\mathbb{F}} \frac{I^i_{t+h}}{\bar{I}_{t+h}} \frac{d\log(I^i_{t+h}/K^i_{t+h})}{d\varepsilon_t^m}. \tag{20}$$

Thus, we can use the right side of (20), that is, the average cross-sectional semielasticity of investment rates to money shocks transmitted through the q-channel (weighted by firm's investment shares), as an (upper bound) estimate for the (negative) semielasticity of aggregate investment to money shocks transmitted through the q-channel.[54]

Based on the estimates reported in figure 6, our estimate for $d\log(\bar{I}_{t+4})/d\varepsilon_t^m$ equals -0.003578, which means that a 1 standard deviation surprise increase in the policy rate changes aggregate investment of Compustat firms by -0.3578% 4 quarters after the shock. The standard deviation of ε_t^m is 9.66 bp in our sample, so this estimate implies a 0.93% decline in investment in response to a 25 bp surprise increase in the fed funds rate. Since it is customary to express this semielasticity

[54] For a derivation of (20), see lemma 6 (app. A).

in terms of changes in the policy rate (instead of surprise changes in the policy rate), we note that, on average, in our sample, for every 3 bp change in the policy rate, about 1 bp is a surprise change (as measured by the change in the fed funds futures rate).[55] Hence, our estimate for $d\log(\bar{I}_{t+4})/d\varepsilon_t^m$ based on (20) implies a 0.31% decline in investment of Compustat firms in response to a 25 bp increase in the fed funds rate. The share of aggregate nonresidential investment by publicly traded firms in the United States is about 0.45 (Asker, Farre-Mensa, and Ljungqvist 2011), so our estimate implies a 0.14% decline in aggregate investment in response to a 25 bp increase in the fed funds rate operating exclusively through the q-channel.[56] By way of comparison, Christiano, Eichenbaum, and Evans (2005) report a peak response in aggregate investment of about 0.4% to a 25 bp decline in the policy rate.[57] To summarize: our micro estimates imply that the q-channel accounts for about one-third of the conventional estimate of the peak response of aggregate investment to monetary policy shocks.

VI. Quantitative Analysis

In this section, we assess the ability of the theory to match the dynamic responses of investment through the q-channel documented in section IV. To this end, we generalize the model of section II along three dimensions.

First, we introduce a monetary policy shock in the form of an unexpected change in the path of the nominal policy rate, r_t (defined in [7]). Specifically, we assume that following the unexpected policy shock $\varepsilon^m \in \mathbb{R}$, the policy rate follows an autoregressive path, $r_{t+1} = \bar{r} + \rho_n(r_t - \bar{r})$, with $\rho_n \in (0, 1)$ and $r_0 = \bar{r} + \varepsilon^m$, where $\bar{r} \in \mathbb{R}_+$ is the steady-state policy rate.

Second, we introduce a stochastic fixed cost of equity issuance. Specifically, an entrepreneur with capital stock k_t who issues or repurchases equity in the second subperiod of period t (i.e., chooses $e_t^i \neq 0$) bears a disutility cost $\xi_t k_t$, where $\xi_t \in \mathbb{R}_+$ is the realization of a uniform random variable independently distributed across entrepreneurs and over time, with support $[0, \bar{\xi}]$.[58]

[55] We obtain this estimate by regressing quarterly changes in the fed funds rate on our series of surprise changes in the fed funds rate, $\{\varepsilon_t^m\}$. With both expressed in basis points, the estimated coefficient is 2.98, so a 25 bp increase in the fed funds rate is associated with a 8.39 bp surprise increase in the fed funds rate.

[56] This last estimate assumes that the q-channel is inoperative for firms not publicly traded. However, it will be an underestimate to the extent that equity stakes on firms not publicly traded are sometimes traded—albeit privately, in OTC-style markets rather than in public organized exchanges.

[57] Figure 1 in Christiano, Eichenbaum, and Evans (2005), e.g., shows that a 60 bp decrease in the policy rate is associated with a 1% increase in aggregate investment 8 quarters after the shock, which is the peak response according to their estimation.

[58] The practical motivation for introducing the equity issuance cost is that it delivers a nontrivial distribution of liquid asset holdings and at the same time makes the model

Third, we assume that in addition to producing $z \in \mathbb{R}_+$ units of good 1 at the end of the first subperiod, each unit of installed capital also delivers $\tilde{z} \in \mathbb{R}_+$ units of good 2 in the second subperiod. Each equity share represents ownership of a unit of capital along with the stream of dividends of good 1 and good 2 produced by that unit of capital. In addition, we assume that instead of paying out the $\tilde{z}s_t$ units of good 2 to the shareholders, the entrepreneur retains this dividend to either augment the capital stock or acquire government bonds and issues $\tilde{e}_t = \tilde{z}s_t/\phi_t^s$ equity claims on the newly created capital to the shareholders (without bearing the fixed cost of issuance).[59]

A. *Calibration*

We let a model period correspond to a quarter and set $\beta = 0.995$, $\delta = 0.025$, $1 - \pi = 0.017$ (the exit rate targeted by Begenau and Salomao 2019), and $\alpha = \theta = 1$ (corresponding to a frictionless stock market that abstracts from microlevel pricing frictions induced by search bargaining). The distribution of financial investors' valuations of the good 1 dividend, G, is assumed to be lognormal, that is, $\log \varepsilon_t \sim \mathcal{N}(\mu_\varepsilon, \sigma_\varepsilon)$, with $\mu_\varepsilon = -\sigma_\varepsilon^2/2$. The value of σ_ε is chosen so that the stock price response to the money shock in the model is in line with the price response to the money shock of stocks with median turnover in our sample. The monetary policy parameters are $\rho_n = 0.5$, $\bar{r} = 0.04/4$, and we choose the size of the policy shock, ε^m, so as to induce a 1% increase in stock prices (conditional on other parameter values). We assume all entrepreneurs enter with a given ratio of (claims to) good 2 to capital, $\omega_0 \equiv w_0/k_0 \in \mathbb{R}_{++}$, and set $\omega_0 = 2/3$, which is consistent with an average ratio of cash to assets of approximately 0.40 for firms upon entering the Compustat sample (e.g.,

flexible enough to match the empirical frequency of equity issuance (the fraction of firms that issue equity in any given quarter).

[59] Conceptually, this assumption captures the idea that firms can also finance investment with retained earnings, which economizes on equity issuance costs. The practical motivation for the assumption is that it allows a more flexible mapping between capital accumulation and the size of the fixed cost of equity issuance. If we did not allow firms to finance investment through retained earnings, then a fixed cost that is high enough to match the (relatively low) empirical frequency of equity issuance also tends to imply an average investment rate that is too low relative to our empirical target. Notice that shareholders are indifferent between receiving $\tilde{z}s_t$ units of good 2 or $\tilde{e}_t$ equity shares each worth ϕ_t^s units of good 2. And since the shadow value of good 2 is higher for entrepreneurs than for shareholders (because entrepreneurs have a higher valuation of the dividend of good 1 that results from investment of good 2 than shareholders), an entrepreneur always prefers retaining the earnings $\tilde{z}s_t$ of good 2 and issuing equity shares worth $\tilde{e}_t\phi_t^s$ units of good 2, rather than paying out the $\tilde{z}s_t$ units of good 2 to investors as dividend. Thus, the capital structure assumption implicit in our treatment of the capital return of good 2 is compatible with the agents' incentives.

Begenau and Palazzo 2021).[60] For any investment rate $\iota \in \mathbb{R}_+$, we assume the adjustment cost is $\Psi(\iota) = \psi(\iota - \delta)^2$, with $\psi \in \mathbb{R}_+$. We calibrate the values of ε_e, z, $\tilde{z}$, $\bar{\xi}$, and ψ so that the stationary equilibrium of our model matches the following five moments from the sample of Compustat firms used in our empirical analysis of section IV: (i) median liquidity ratio, (ii) median capital expenditures to capital ratio for firms with below-median liquidity ratio, (iii) median capital expenditures to capital ratio for firms with above-median liquidity ratio, (iv) unconditional frequency of equity issuance across firms and time, and (v) average ratio of equity issuance relative to total assets conditional on equity issuance.[61] Table 1 summarizes the calibration targets and the resulting parameter values.

B. *Results*

In this section, we compare the theoretical and empirical impulse responses of investment to a money shock that induces a 1% increase in stock prices at impact. To obtain the model counterparts of the impulse responses estimated in section IV.C, we calculate the average dynamic responses of log capital expenditures for a large sample of firms drawn from the invariant distribution of the model.[62]

[60] The entrepreneur's problem is homogeneous of degree 1 in capital, so we need only specify the ratio of good 2 to capital of entrants. Also, although we assume all entrepreneurs are identical upon entry, two idiosyncratic shocks (i.e., the fixed cost of equity issuance and the exit shock) lead to ex post heterogeneity in entrepreneurs' balance sheets.

[61] We follow the standard practice in the corporate finance literature of classifying a firm i as "issuing equity" if the ratio of net equity issuance to assets, e_t^i, exceeds a specified threshold. One rationale for this practice is that, as pointed out by McKeon (2015), the timing of the proceeds from stock sales reported in firms' financial statements may reflect employees' decisions to exercise stock options rather than a managerial decision to sell stock, which is the relevant decision for our purposes. Since firm-initiated equity issuances tend to be large and infrequent, McKeon (2015) proposes using an issuance threshold as a reliable way to identify equity issuances that contain a firm-initiated component. Leary and Roberts (2005), e.g., use a cutoff of 5% when working with annual Compustat data. We correspondingly adopt a cutoff of 5% /4 = 1.25% for our quarterly analysis.

[62] In our model, monetary policy affects only investment through its effect on the equity prices of equity-dependent firms. So we do not face the identification problem discussed in sec. III.C when working with model-generated data. The procedure to compute the impulse responses in the quantitative model is as follows: (1) Compute the stationary equilibrium, which involves computing the invariant distribution of liquid assets and outstanding equity (per unit of capital) across firms. (2) Draw a random sample of 20,000 firms from the stationary distribution and label them as "low-liquidity" or "high-liquidity" depending on whether their ratio of liquid assets to capital is below or above the median of the stationary distribution. (3) Simulate the equilibrium path for each of these firms by drawing 13 realizations of the fixed equity issuance shock. (4) Redo step 3 (for the same sample of firms and conditional on the same realizations of equity issuance shocks), but instead of keeping the policy rate constant at the steady-state level as in step 3, assume it follows the autoregressive process described in the text (assuming firms have perfect foresight of the policy rate following the unexpected shock ε^m in the first of the 13 periods). (5) For each firm and each of the 13 periods, compute the difference between the log capital expenditures to capital ratios in steps 4 and 3. (6) Taking the average of these log differences across

TABLE 1
Calibrated Parameter Values and Calibration Targets

	A. Externally Calibrated	
	Value	Target/Source
β	.995	2% annual real rate
$\bar{r}$	.04/4	4% annualized nominal rate
δ	.025	Conventional
$1 - \pi$	.017	Compustat exit (Begenau and Salomao 2019)
σ_ε	2.56	Top 10% turnover ϕ_t^i response to market price
$(\alpha, \theta, \mu_\varepsilon)$	$(1, 1, -\sigma_\varepsilon^2/2)$	Normalization (Lagos and Zhang 2020)
ω_0	2/3	Mean cash-to-assets at initial public offering (Begenau and Palazzo 2021)

	B. Internally Calibrated			
	Value	Moment	Data	Model
z	.0195	Median (ℓ_t^i)	.086	.089
$\tilde{z}$	.0289	Median $(I_t^i/K_t^i)\|_{\mathbb{I}_{L,t-1}=1}$	.039	.042
ε_e	4.008	Median $(I_t^i/K_t^i)\|_{\mathbb{I}_{L,t-1}=0}$	.056	.052
$\bar{\xi}$	.145	Frequency $(\mathrm{e}_t^i > .05/4)$	.080	.077
ψ	45.318	Mean $(\mathrm{e}_t^i)\|_{\mathrm{e}_t^i>.05/4}$	.157	.152

Figure 7 depicts the theoretical impulse responses of log capital expenditure rates alongside the corresponding point estimates and confidence intervals presented in figure 4*B*. In the theory, firms with liquidity ratios below the median of the invariant distribution increase their investment by roughly 1% on average in response to a monetary shock that increases Tobin's q by 1%. The path of the average response of low-liquidity firms is very similar in the model and the data. The average theoretical response for firms with liquidity ratios above the median of the invariant distribution is considerably smaller, consistent with our finding no evidence of the q-channel affecting the investment of high-liquidity firms in the data.[63]

all sampled high- and low-liquidity firms, respectively, yields an average response path conditional on the shock ε^m. Because of possible nonlinearities, we repeat this procedure for a positive and a negative money shock, corresponding to an absolute 1% impact effect on the stock price. The impulse response in fig. 7 reports the average of these two paths (with the contractionary shock response signs "flipped'' accordingly).

[63] The average investment response of high-liquidity firms in this model with long-lived entrepreneurs is not exactly zero, e.g., as it was in the simpler model with 2-period lived entrepreneurs of sec. II.B. This happens for two reasons. First, in any period when there is a reduction in the policy rate, some firms with above-median liquidity ratios are getting low enough draws of the equity issuance cost, ξ_t, and take advantage of the beneficial conditions to issue equity. Second, because the monetary shock is persistent and its effect on stock prices lasts for several periods, firms with liquidity ratios that are higher than the median but still relatively low anticipate they will be issuing equity soon, which combined with the investment-smoothing motive introduced by the convex adjustment cost, induces them to increase investment financed with their own liquid asset holdings starting from the time of the money shock (even though they may not yet be accessing the equity market).

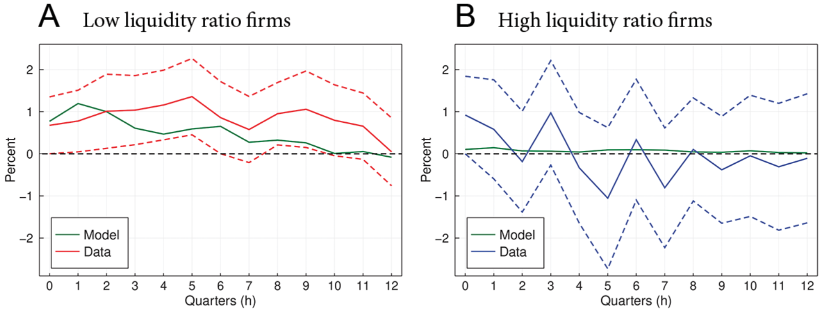

FIG. 7.—Comparison of capital expenditures responses from model and data estimates. "Data" refers to point estimates and 95% confidence intervals for γ_h and $\gamma_h + \tilde{\gamma}_h$ from specification (16) with $y_t^i = x_t^i$ as the outcome variable. "Model" response is computed as the average firm-level impulse response of log capital expenditures to capital, 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 cash-to-assets ratio in both the model and the data.

VII. Conclusion

Over 50 years ago, Tobin (1969) outlined a "general equilibrium approach to monetary theory" proposing that the principal way in which financial policies and events affect the economy is by changing the valuation of physical assets relative to their replacement cost—a variable he denoted "q." Since then, Tobin's q has played a key role in the theory of Investment, but—despite being its raison d'être—the role of Tobin's q in the transmission of monetary shocks subsists only in undergraduate textbook narratives of a long list of plausible monetary transmission mechanisms.

In this paper, we have taken two steps toward (re-)establishing Tobin's q as a major conduit between monetary policy and the real economy. First, we have developed an empirical identification strategy for the q-channel and have used it to quantify its relevance in the transmission of monetary policy to the capital structure and investment decisions of the corporate sector in the United States. Second, we have developed a theoretical model that clarifies the roles that financial constraints (as a determinant of a firm's dependence on equity financing for investment), the stock market (as a mechanism where outside investors determine the market price of equity claims on firms), and money (as a means of payment in financial trades among outside investors) play in the transmission of monetary policy shocks through stock prices. We hope the identification strategy and the theoretical mechanisms that we have described here will be useful in studying the effects of other financial or policy shocks on the economy.

Data Availability

Code replicating the tables and figures in this article can be found in the Harvard Dataverse: https://doi.org/10.7910/DVN/WM2VSE (Jeenas and Lagos 2023).

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