Abstract

We provide empirical evidence of a novel liquidity-based transmission mechanism through which monetary policy influences asset markets, develop a dynamic stochastic monetary equilibrium model of this mechanism, and use it to assess the ability of the quantitative theory to match the evidence.

Keywords: Asset prices; Liquidity; Monetary policy; Monetary transmission

JEL classification: D83, E52, G12
1 Introduction

In most modern economies central banks implement monetary policy indirectly, by intervening in certain financial markets (e.g., in the United States, the Fed Funds market and the market for Treasuries). The underlying idea is that the effects those interventions have on asset prices will be transmitted to the rest of the economy to help achieve the ultimate policy objectives. Thus, quantifying and understanding the transmission mechanism of monetary policy to asset prices is necessary for understanding how monetary policy operates.

In this paper we conduct an empirical, theoretical, and quantitative study of the effects of monetary policy on financial markets in general and the equity market in particular. Specifically, we make three contributions. First, we provide empirical evidence of a novel channel through which monetary policy influences financial markets: Tight money increases the opportunity cost of holding the nominal assets used routinely to settle financial transactions (e.g. bank reserves, real money balances), making these payment instruments scarcer. In turn, this scarcity reduces the resalability and turnover of financial assets, and this increased illiquidity leads to a reduction in price. We label this mechanism the turnover-liquidity (transmission) mechanism (of monetary policy). Second, to get a better understanding of this mechanism, we develop a theory of trade in financial over-the-counter (OTC) markets (that nests the competitive benchmark as a special case), in which money is used as a means of payment in financial transactions. The model shows how the details of the market microstructure and the quantity of money shape the performance of financial markets (e.g., as gauged by standard measures of market liquidity), contribute to the determination of asset prices (e.g., through the resale option value of assets), and—consistent with the evidence we document—offer a liquidity based explanation for the negative correlation between real stock returns and unexpected increases in the nominal interest rate that is used to implement monetary policy. Third, we bring the theory to the data. We calibrate a generalized version of the basic model and use it to conduct a number of quantitative theoretical exercises designed to assess the ability of the theory to match the empirical effects of monetary policy on asset prices, both on policy announcement days and at longer horizons.

The rest of the paper is organized as follows. Section 2 presents the basic model. It considers a setting in which a financial asset that yields a dividend flow of consumption goods (e.g., an equity or a real bond) is demanded by investors who have time-varying heterogeneous
valuations for the dividend. To achieve the gains from trade that arise from their heterogeneous private valuations, investors participate in a bilateral market with random search that is intermediated by specialized dealers who have access to a competitive interdealer market. In the dealer-intermediated bilateral market, which has many of the stylized features of a typical OTC market structure but also nests the perfectly competitive market structure as a special case, investors and dealers seek to trade the financial asset using money as a means of payment. Periodically, dealers and investors are also able to rebalance their portfolios in a conventional Walrasian market. Section 3 describes the efficient allocation. Equilibrium is characterized in Section 4. In Section 5 we present the main implications of the theory. Asset prices and conventional measures of financial liquidity (e.g., spreads, trade volume, and dealer supply of immediacy) are determined by the quantity of money and the details of the microstructure where the asset trades (e.g., the degree of market power of dealers and the ease with which investors find counterparties). Generically, asset prices in the monetary economy exhibit a speculative premium (or speculative “bubble”) whose size varies systematically with the market microstructure and the monetary policy stance. For example, a high anticipated opportunity cost of holding money reduces equilibrium real balances and distorts the asset allocation by causing too many assets to remain in the hands of investors with relatively low valuations, depressing real asset prices. Section 6 is purely empirical. In it we confirm the finding, documented in previous empirical work, that surprise increases in the nominal policy rate cause sizable reductions in real stock returns on FOMC announcement days. A 1 percentage point unexpected increase in the policy rate causes a decrease of between 4 and 6 percentage points in the stock market return on the day of the policy announcement. In addition, this section contains two new empirical findings. First, we document that episodes of unexpected policy tightening are also associated with large and persistent declines in stock turnover. Second, we find evidence that the magnitude of the reduction in return caused by the policy tightening is significantly larger for stocks that are normally traded more actively, e.g., stocks with higher turnover rates. For example, in response to an unexpected increase in the policy rate, the announcement-day decline in the return of a stock in the 95th percentile of turnover rates is about twelve times larger than that of a stock in the 5th percentile. The empirical evidence in this section suggests a mechanism whereby monetary policy affects asset prices through a reduction in turnover liquidity. In Section 7 we formulate, calibrate, and simulate a generalized version of the basic model and use it to assess the ability of the theory to fit the empirical evidence on the effects
of monetary shocks on aggregate stock returns as well as the new cross-sectional evidence on the turnover-liquidity transmission mechanism. This paper is related to four areas of research: search-theoretic models of money, search-theoretic models of financial trade in OTC markets, resale-option theories of asset-price bubbles, and an extensive empirical literature that studies the effects of monetary policy on asset prices. Section 8 places our contribution in the context of these related literatures. Section 9 concludes. Appendix A contains all proofs. Appendix B contains supplementary material.

2 Model

Time is represented by a sequence of periods indexed by \( t = 0, 1, \ldots \). Each time-period is divided into two subperiods where different activities take place. There is a continuum of infinitely lived agents called investors, each identified with a point in the set \( I = [0, 1] \). There is also a continuum of infinitely lived agents called dealers, each identified with a point in the set \( D = [0, 1] \). All agents discount payoffs across periods with the same factor, \( \beta \in (0, 1) \). In every period there is a continuum of active production units with measure \( A^s \in \mathbb{R}^{++} \). Every active unit yields an exogenous dividend \( y_t \in \mathbb{R}_+ \) of a perishable consumption good at the end of the first subperiod of period \( t \). (Each active unit yields the same dividend as every other active unit so \( y_t A^s \) is the aggregate dividend.) At the beginning of every period \( t \), every active unit is subject to an independent idiosyncratic shock that renders it permanently unproductive with probability \( 1 - \delta \in [0, 1) \). If a production unit remains active, its dividend in period \( t + 1 \) is \( y_{t+1} = \gamma_{t+1} y_t \) where \( \gamma_{t+1} \) is a nonnegative random variable with cumulative distribution function \( \Gamma \), i.e., \( \text{Pr}(\gamma_{t+1} \leq \gamma) = \Gamma(\gamma) \), and mean \( \bar{\gamma} \in (0, (\beta \delta)^{-1}) \). The time-\( t \) dividend becomes known to all agents at the beginning of period \( t \), and at that time each failed production unit is replaced by a new unit that yields dividend \( y_t \) in the initial period and follows the same stochastic process as other active units thereafter (the dividend of the initial set of production units, \( y_0 \in \mathbb{R}^{++} \), is given at \( t = 0 \)). In the second subperiod of every period, every agent has access to a linear production technology that transforms effort into another kind of perishable homogeneous consumption good.

For each active production unit there is one durable and perfectly divisible equity share that represents the bearer’s ownership of the production unit and confers him the right to collect dividends. At the beginning of every period \( t \geq 1 \), each investor receives an endowment of \( (1 - \delta) A^s \) equity shares corresponding to the new production units. (When a production
unit fails, its equity share disappears.) There is a second financial instrument, money, which is intrinsically useless (it is not an argument of any utility or production function, and unlike equity, ownership of money does not constitute a right to collect any resources). The stock of money at time \( t \) is denoted \( A_m^t \). The initial stock of money, \( A_m^0 \in \mathbb{R}^{++} \), is given and \( A_m^{t+1} = \mu A_m^t \), with \( \mu \in \mathbb{R}^{++} \). A monetary authority 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 a portfolio of equity shares and money. All financial instruments are perfectly recognizable, cannot be forged, and can be traded in every subperiod.

In the second subperiod of every period, all agents can trade the consumption good produced in that subperiod, equity shares, and money, in a spot Walrasian market. In the first subperiod of every period, trading is organized as follows. Investors can trade equity shares and money in a random bilateral OTC market with dealers, while dealers can also trade equity shares and money with other dealers in a spot Walrasian interdealer market. We use \( \alpha \in [0,1] \) to denote the probability that an individual investor is able to make contact with a dealer in the OTC market. (The probability that a dealer contacts an investor is also \( \alpha \).) Once a dealer and an investor have contacted each other, the pair negotiates the quantity of equity shares and money that the dealer will trade in the interdealer market on behalf of the investor and an intermediation fee for the dealer’s intermediation services. We assume the terms of the trade between an investor and a dealer in the OTC market are determined by Nash Bargaining where \( \theta \in [0,1] \) is the investor’s bargaining power. The timing assumption is that the round of OTC trade takes place in the first subperiod and ends before production units yield dividends. Hence equity is traded cum dividend in the OTC market (and in the interdealer market) of the first subperiod, but ex dividend in the Walrasian market of the second subperiod.\(^1\) Asset 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.

An individual dealer’s preferences are represented by

\[
\mathbb{E}_0^d \sum_{t=0}^{\infty} \beta^t (c_{dt} - h_{dt})
\]

where \( c_{dt} \) is his consumption of the homogeneous good that is produced, traded and consumed

\(^1\)As in search models of OTC markets, e.g., see Duffie et al. (2005) and Lagos and Rocheteau (2009), an investor must own the equity share in order to consume the dividend.
in the second subperiod of period \( t \), and \( h_{it} \) is the utility cost from exerting \( h_{it} \) units of effort to produce this good. The expectation operator \( E^d_0 \) is with respect to the probability measure induced by the dividend process and the random trading process in the OTC market. Dealers get no utility from the dividend good.\(^2\) An individual investor’s preferences are represented by
\[
E_0 \sum_{t=0}^{\infty} \beta^t (\varepsilon_{it} y_{it} + c_{it} - h_{it})
\]
where \( y_{it} \) is the quantity of the dividend good that investor \( i \) consumes at the end of the first subperiod of period \( t \), \( c_{it} \) is his consumption of the homogeneous good that is produced, traded and consumed in the second subperiod of period \( t \), and \( h_{it} \) is the utility cost from exerting \( h_{it} \) units of effort to produce this good. The variable \( \varepsilon_{it} \) denotes the realization of a valuation shock that is distributed independently over time and across agents, with a differentiable cumulative distribution function \( G \) on the support \([\varepsilon_L, \varepsilon_H] \subseteq [0, \infty]\), and \( \bar{\varepsilon} = \int \varepsilon dG(\varepsilon) \). Investor \( i \) learns his realization \( \varepsilon_{it} \) at the beginning of period \( t \), before the OTC trading round. The expectation operator \( E_0 \) is with respect to the probability measure induced by the dividend process, the investor’s valuation shock, and the random trading process in the OTC market.

3 Efficiency

Consider a social planner who wishes to maximize the sum of all agents’ expected discounted utilities subject to the same meeting frictions that agents face in the decentralized formulation. Specifically, in the first subperiod of every period, the planner can only reallocate assets among all dealers and the measure \( \alpha \) of investors who contact dealers at random. We restrict attention to symmetric allocations (identical agents receive equal treatment). Let \( c_{Dt} \) and \( h_{Dt} \) denote a dealer’s consumption and production of the homogeneous consumption good in the second subperiod of period \( t \). Let \( c_{It} \) and \( h_{It} \) denote an investor’s consumption and production of the homogeneous consumption good in the second subperiod of period \( t \). Let \( \tilde{a}_{Dt} \) denote the beginning-of-period-\( t \) (before depreciation) equity holding of a dealer, and let \( a_{Dt}^\prime \) denote the equity holding of a dealer at the end of the first subperiod of period \( t \) (after OTC trade). Let \( \tilde{a}_{It} \) denote the beginning-of-period-\( t \) (before depreciation and endowment) asset holding of an investor. Finally, let \( a_{It}^\prime \) denote a measure on \( \mathcal{F} ([\varepsilon_L, \varepsilon_H]) \), the Borel \( \sigma \)-field defined on \([\varepsilon_L, \varepsilon_H]\).

\(^2\)This assumption implies that dealers have no direct consumption motive for holding the equity share. It is easy to relax, but we adopt it because it is the standard benchmark in the search-based OTC literature, e.g., see Duffie et al. (2005) and Lagos and Rocheteau (2009), Lagos, Rocheteau and Weill (2011), and Weill (2007).
The measure \( a'_{It} \) is interpreted as the distribution of post-OTC-trade asset holdings among investors with different valuation types who contacted a dealer in the first subperiod of period \( t \). With this notation, the planner’s problem consists of choosing a nonnegative allocation,

\[
\left\{ \left[ \tilde{a}_{jt}, a'_{jt}, c_{jt}, h_{jt} \right]_{j \in \{D,I\}} \right\}_{t=0}^{\infty},
\]

to maximize

\[
E_0 \sum_{t=0}^{\infty} \beta^t \left[ \alpha \int_{\varepsilon_L}^{\varepsilon_H} \varepsilon y_{It} a'_{It} (d\varepsilon) + (1 - \alpha) \int_{\varepsilon_L}^{\varepsilon_H} \varepsilon y_{It} a_{It} dG (\varepsilon) + c_{Dt} + c_{It} - h_{Dt} - h_{It} \right]
\]

(the expectation operator \( E_0 \) is with respect to the probability measure induced by the dividend process) subject to

\[
\begin{align*}
\tilde{a}_{Dt} + \tilde{a}_{It} & \leq A^s \\
 a'_{Dt} + \alpha \int_{\varepsilon_L}^{\varepsilon_H} a'_{It} (d\varepsilon) & \leq a_{Dt} + \alpha a_{It} \\
c_{Dt} + c_{It} & \leq h_{Dt} + h_{It} \\
a_{Dt} & = \delta \tilde{a}_{Dt} \\
a_{It} & = \delta \tilde{a}_{It} + (1 - \delta) A^s.
\end{align*}
\]

**Proposition 1** The efficient allocation satisfies the following two conditions for every \( t \): (a) \( \tilde{a}_{Dt} = A^s - \tilde{a}_{It} = A^s \) and (b) \( a'_{It} (E) = \mathbb{1}_{\{\varepsilon_H \in E\}} \left[ \delta + \alpha (1 - \delta) \right] A^s / \alpha \), where \( \mathbb{1}_{\{\varepsilon_H \in E\}} \) is an indicator function that takes the value 1 if \( \varepsilon_H \in E \), and 0 otherwise, for any \( E \in \mathcal{F} ([\varepsilon_L, \varepsilon_H]) \).

According to Proposition 1, the efficient allocation is characterized by the following two properties: (a) only dealers carry equity between periods and (b) among those investors who have a trading opportunity with a dealer, only those with the highest valuation type hold equity shares at the end of the first subperiod.

**4 Equilibrium**

We begin by considering the determination of the terms of trade in a bilateral meeting in the OTC round of period \( t \) between a dealer with portfolio \( a_{dt} \) and an investor with portfolio \( a_{it} \) and valuation type \( \varepsilon \). Let \( \bar{a}_t = (\bar{a}^m_t, \bar{a}^s_t) \) denote the investor’s post-trade portfolio and let \( k_t \) denote the intermediation fee the dealer charges for his intermediation services. We assume
the intermediation fee is expressed in terms of the general good and paid by the investor in the second subperiod.\textsuperscript{3} We take \((\bar{\pi}_t, k_t)\) to be determined by the Nash bargaining solution where the investor has bargaining power \(\theta \in [0, 1]\). Let \(\hat{W}^D_t(\mathbf{a}_{dt}, k_t)\) denote the maximum expected discounted payoff of a dealer with portfolio \(\mathbf{a}_{dt}\) and earned fee \(k_t\) when he reallocates his portfolio in the interdealer market of period \(t\). Let \(W^I_t(\mathbf{a}_{dt}, -k_t)\) denote the maximum expected discounted payoff at the beginning of the second subperiod of period \(t\) (after the production units have borne dividends) of an investor who is holding portfolio \(\mathbf{a}_{dt}\) and has to pay a dealer fee \(k_t\). For each \(t\), define a pair of functions \(\pi^k_t : \mathbb{R}^2_+ \times [\varepsilon_L, \varepsilon_H] \rightarrow \mathbb{R}_+\) for \(k = m, s\) and a function \(k_t : \mathbb{R}^2_+ \times [\varepsilon_L, \varepsilon_H] \rightarrow \mathbb{R}\), and let \(\bar{\mathbf{a}}_t(\mathbf{a}_{dt}, \varepsilon) = (\pi^m_t(\mathbf{a}_{dt}, \varepsilon), \pi^s_t(\mathbf{a}_{dt}, \varepsilon))\) for each \((\mathbf{a}_{dt}, \varepsilon)\) \(\in \mathbb{R}^2_+ \times [\varepsilon_L, \varepsilon_H]\). We use \([\bar{\mathbf{a}}_t(\mathbf{a}_{dt}, \varepsilon), k_t(\mathbf{a}_{dt}, \varepsilon)]\) to represent the bargaining outcome for a bilateral meeting at time \(t\) between an investor with portfolio \(\mathbf{a}_{dt}\) and valuation type \(\varepsilon\), and a dealer with portfolio \(\mathbf{a}_{dt}\). That is, \([\bar{\mathbf{a}}_t(\mathbf{a}_{dt}, \varepsilon), k_t(\mathbf{a}_{dt}, \varepsilon)]\) is the solution to

\[
\max_{(\bar{\pi}_t, k_t) \in \mathbb{R}^2_+ \times \mathbb{R}} \left[ \varepsilon y_\bar{\pi}_t^m + W^I_t(\bar{\pi}_t, -k_t) - \varepsilon y_\bar{\pi}_t^s - W^I_t(\mathbf{a}_{dt}, 0) \right]^\theta \left[ \hat{W}^D_t(\mathbf{a}_{dt}, k_t) - \hat{W}^D_t(\mathbf{a}_{dt}, 0) \right]^{1-\theta} \tag{6}
\]

s.t. \(\bar{\pi}_t^m + p_t \pi_t^s \leq a_t^m + p_t a_t^s\)

\(\hat{W}^D_t(\mathbf{a}_{dt}, 0) \leq \hat{W}^D_t(\mathbf{a}_{dt}, k_t)\)

\(\varepsilon y_t a_t^s + W^I_t(\mathbf{a}_{dt}, 0) \leq \varepsilon y_t \pi_t^s + W^I_t(\bar{\pi}_t, -k_t)\)

where \(p_t\) is the dollar price of equity in the interdealer market of period \(t\).

Let \(W^D_t(\mathbf{a}_t, k_t)\) denote the maximum expected discounted payoff of a dealer who has earned fee \(k_t\) in the OTC round of period \(t\) and, at the beginning of the second subperiod of period \(t\), is holding portfolio \(\mathbf{a}_t\). Then the dealer’s value of trading in the interdealer market is

\(
\hat{W}^D_t(\mathbf{a}_t, k_t) = \max_{\hat{\mathbf{a}}_t \in \mathbb{R}^2_+} W^D_t(\hat{\mathbf{a}}_t, k_t) \tag{7}
\)

s.t. \(\hat{a}_t^m + p_t \hat{a}_t^s \leq a_t^m + p_t a_t^s\)

where \(\hat{\mathbf{a}}_t \equiv (\hat{a}_t^m, \hat{a}_t^s)\). For each \(t\), define a pair of functions \(\hat{\pi}_t^k : \mathbb{R}^2_+ \rightarrow \mathbb{R}_+\) for \(k = m, s\), and let \(\hat{\mathbf{a}}_t(\mathbf{a}_t) = (\hat{a}_t^m(\mathbf{a}_t), \hat{a}_t^s(\mathbf{a}_t))\) denote the solution to (7).

Let \(V^D_t(\mathbf{a}_t)\) denote the maximum expected discounted payoff of a dealer who enters the OTC round of period \(t\) with portfolio \(\mathbf{a}_t \equiv (a_t^m, a_t^s)\). Let \(\phi_t \equiv (\phi_t^m, \phi_t^s)\), where \(\phi_t^m\) is the real

\textsuperscript{3}In the working-paper version of this model (Lagos and Zhang, 2015) we instead assume the investor must pay the intermediation fee on the spot, i.e., with money or equity. The alternative formulation we use here makes the analysis and the exposition much simpler while the main economic mechanisms are essentially unchanged.
price of money and \( \phi^*_t \) the real \textit{ex dividend} price of equity in the second subperiod of period \( t \) (both expressed in terms of the second-subperiod consumption good). Then,

\[
W^D_t(a_t, k_t) = \max_{(c_t, h_t, \hat{a}_{t+1}) \in \mathbb{R}^+_t} \left[ c_t - h_t + \beta \mathbb{E}_t V^{D}_{t+1}(a_{t+1}) \right] \\
\text{s.t. } c_t + \phi_t \hat{a}_{t+1} \leq h_t + k_t + \phi_t a_t
\]

where \( \hat{a}_{t+1} = (\hat{a}^m_{t+1}, \hat{a}^s_{t+1}) \), \( a_{t+1} = (\hat{a}^m_{t+1}, \delta \hat{a}^s_{t+1}) \), \( \mathbb{E}_t \) is the conditional expectation over the next-period realization of the dividend, and \( \phi_t a_t \) denotes the dot product of \( \phi_t \) and \( a_t \). Similarly, let

\[
V^I_t(a_t, \varepsilon) = \text{the maximum expected discounted payoff of an investor with valuation type } \varepsilon \text{ and portfolio } a_t \equiv (a^m_t, a^s_t) \text{ at the beginning of the OTC round of period } t.
\]

Then, \( V^I_t(a_t, \varepsilon) \) is the value function of an investor who enters the OTC round of period \( t \) with portfolio \( a_t \) and valuation type \( \varepsilon \) is

\[
V^I_t(a_t, \varepsilon) = \alpha \left\{ \varepsilon y_t a^m_t(a_t, \varepsilon) + W^I_t(\pi_t(a_t, \varepsilon), -k_t(a_t, \varepsilon)) \right\} + (1 - \alpha) \left\{ \varepsilon y_t a^s_t + W^I_t(a_t, 0) \right\}.
\]

The value function of a dealer who enters the OTC round of period \( t \) with portfolio \( a_t \) is

\[
V^D_t(a_t) = \alpha \int \tilde{W}^D_t[a_t, k_t(a_t, \varepsilon)] dH_{it}(a_t, \varepsilon) + (1 - \alpha) \tilde{W}^D_t(a_t, 0)
\]

where \( H_{it} \) is the joint cumulative distribution function over the portfolios and valuation types of the investors the dealer may contact in the OTC market of period \( t \).

Let \( j \in \{ D, I \} \) denote the agent type, i.e., \( "D" \) for dealers and \( "I" \) for investors. Then for \( j \in \{ D, I \} \), let \( A^m_{jt} \) and \( A^s_{jt} \) denote the quantities of money and equity shares, respectively, held by all agents of type \( j \) at the beginning of the OTC round of period \( t \) (after production units have depreciated and been replaced). That is, \( A^m_{jt} = \int a^m_t dF_{jt}(a_t) \) and \( A^s_{jt} = \int a^s_t dF_{jt}(a_t) \), where \( F_{jt} \) is the cumulative distribution function over portfolios \( a_t = (a^m_t, a^s_t) \) held by agents of type \( j \) at the beginning of the OTC round of period \( t \). Let \( \tilde{A}^m_{jt+1} \) and \( \tilde{A}^s_{jt+1} \) denote the total quantities of money and shares held by all agents of type \( j \) at the end of period \( t \), i.e., \( \tilde{A}^m_{jt+1} = \int_D \tilde{a}^m_{jt+1} dx \) and \( \tilde{A}^s_{jt+1} = \int_I \tilde{a}^s_{jt+1} di \) for \( k \in \{ s, m \} \), with \( A^m_{Dt+1} = \tilde{A}^m_{Dt+1}, A^s_{Dt+1} = \delta \tilde{A}^s_{Dt+1}, A^m_{It+1} = \tilde{A}^m_{It+1} \). \( 9 \)
and \( A_{t+1}^s = \delta A_t^s + (1 - \delta) A^s \). Let \( A_{Dt}^m \) and \( A_{Dt}^k \) denote the quantities of money and shares held after the OTC round of trade of period \( t \) by all the dealers, and let \( A_{t}^m \) and \( A_t^k \) denote the quantities of money and shares held after the OTC round of trade of period \( t \) by all the investors who are able to trade in the first subperiod. For asset \( k \in \{s, m\} \), \( \hat{A}_{Dt}^k = \int \hat{a}_t^k(\mathbf{a}_t) dF_{Dt}(\mathbf{a}_t) \) and \( \bar{A}_t^k = \alpha \int \bar{\pi}_t^k(\mathbf{a}_t, \varepsilon) dH_t(\mathbf{a}_t, \varepsilon) \). We are now ready to define equilibrium.

**Definition 1** An equilibrium is a sequence of prices, \( \{1/p_t, \phi_t^m, \phi_t^s\}_{t=0}^\infty \), bilateral terms of trade in the OTC market, \( \{\bar{a}_t, k_t\}_{t=0}^\infty \), dealer portfolios, \( \{\langle \tilde{a}_{dt}, \bar{a}_{dt+1}, a_{dt+1} \rangle_{d \in D} \}_{t=0}^\infty \), and investor portfolios, \( \{\langle a_{it+1}, a_{it+1} \rangle_{i \in I} \}_{t=0}^\infty \), such that for all \( t \): (i) the bilateral terms of trade \( \{\bar{a}_t, k_t\}_{t=0}^\infty \) solve (6), (ii) taking prices and the bargaining protocol as given, the portfolios \( \{\tilde{a}_{dt}, \bar{a}_{dt+1}, a_{dt+1} \} \) solve the individual dealer’s optimization problems (7) and (8), and the portfolios \( \langle a_{it+1}, a_{it+1} \rangle \) solve the individual investor’s optimization problem (9), and (iii) prices, \( \{1/p_t, \phi_t^m, \phi_t^s\}_{t=0}^\infty \), are such that all Walrasian markets clear, i.e., \( \tilde{A}_{t+1}^m + \bar{A}_t^m = A^m \) (the end-of-period- \( t \) Walrasian market for equity clears), \( \tilde{A}_{t+1}^k + \bar{A}_t^k = A^k \) (the end-of-period- \( t \) Walrasian market for money clears), and \( \tilde{A}_{Dt}^k + \bar{A}_t^k = A^k + \alpha A^s_t \) for \( k = s, m \) (the period- \( t \) OTC interdealer markets for equity and money clear). An equilibrium is “monetary” if \( \phi_t^m > 0 \) for all \( t \) and “nonmonetary” otherwise.

The following result characterizes the equilibrium post-trade portfolios of dealers and investors in the OTC market, taking beginning-of-period portfolios as given.

**Lemma 1** Define \( \varepsilon_t^s = \frac{p_t \phi_t^m - \phi_t^s}{y_t} \) and

\[
\chi(\varepsilon_t^s, \varepsilon) = \begin{cases} 
1 & \text{if } \varepsilon_t^s < \varepsilon \\
0 & \text{if } \varepsilon_t^s = \varepsilon \\
0 & \text{if } \varepsilon < \varepsilon_t^s .
\end{cases}
\]

Consider a bilateral meeting in the OTC round of period \( t \) between a dealer and an investor with portfolio \( \mathbf{a}_t \) and valuation type \( \varepsilon \). The investor’s post-trade portfolio, \( [\pi_t^m(\mathbf{a}_t, \varepsilon), \pi_t^s(\mathbf{a}_t, \varepsilon)] \), is given by

\[
\pi_t^m(\mathbf{a}_t, \varepsilon) = [1 - \chi(\varepsilon_t^s, \varepsilon)] (a_t^m + p_t a_t^s) \\
\pi_t^s(\mathbf{a}_t, \varepsilon) = \chi(\varepsilon_t^s, \varepsilon) (1/p_t) (a_t^m + p_t a_t^s)
\]

and the intermediation fee charged by the dealer is

\[
k_t(\mathbf{a}_t, \varepsilon) = (1 - \theta) (\varepsilon - \varepsilon_t^s) \left[ \chi(\varepsilon_t^s, \varepsilon) \frac{1}{p_t} a_t^m - [1 - \chi(\varepsilon_t^s, \varepsilon)] a_t^s \right] y_t.
\]
A dealer who enters the OTC market with portfolio $a_{dt}$, exits the OTC market with portfolio $[\hat{a}_t^m(a_{dt}), \hat{a}_t^s(a_{dt})] = [\pi_t^m(a_{dt}, 0), \pi_t^s(a_{dt}, 0)]$.

Lemma 1 offers a full characterization of the post-trade portfolios of investors and dealers in the OTC market. First, the bargaining outcome depends on whether the investor’s valuation, $\varepsilon$, is above or below a cutoff, $\varepsilon^*_t$. If $\varepsilon^*_t < \varepsilon$, the investor uses all his cash to buy equity, i.e., if his pre-trade portfolio is $a_t$, then his post-trade portfolio is $\pi_t^m(a_t, \varepsilon)$, $\pi_t^s(a_t, \varepsilon) = (0, a_t^x + a_t^m/p_t)$. Conversely, if $\varepsilon < \varepsilon^*_t$, then he sells all his equity holding for cash, i.e., his post-trade portfolio is $\pi_t^m(a_t, \varepsilon), \pi_t^s(a_t, \varepsilon) = (a_t^m + p_t a_t^x, 0)$. The intermediation fee earned by the dealer is equal to a share $1 - \theta$ of the investor’s gain from trade. If $\varepsilon^*_t < \varepsilon$, the fee equals $(1 - \theta)(\varepsilon - \varepsilon^*_t) \frac{1}{\bar{p}} a_t^m y_t$. If $\varepsilon < \varepsilon^*_t$, the fee equals $(1 - \theta)(\varepsilon^*_t - \varepsilon) a_t^x y_t$. The dealer’s post-trade portfolio is the same as that of an investor with $\varepsilon = 0$.

For the remainder of the section we specialize the analysis to stationary equilibria. That is, equilibria in which aggregate equity holdings are constant over time, i.e., $A_{Dt}^* = A_{D}^*$ and $A_{Dt}^s = A_{D}^s$ for all $t$, real asset prices are time-invariant linear functions of the aggregate dividend, i.e., $\phi_t^s = \phi^s y_t$, $p_t \phi_t^m \equiv \bar{p}^t = \bar{\phi}^s y_t$, $\phi_t^m A_{Dt}^m = Z y_t$, and $\phi_t^m A_{Dt}^m = Z_D y_t$. Hence, in a stationary equilibrium, $\varepsilon_t = \bar{\varepsilon} - \varepsilon^* \equiv \varepsilon^*, \phi_t^s / \phi_t^s = \gamma_t + 1, \phi_t^m / \phi_t^m = \mu / \gamma_t + 1$, and $p_t + 1 / p_t = \mu$. Throughout the analysis we let $\bar{\beta} \equiv \beta \bar{\gamma}$ and maintain the assumption $\mu > \bar{\beta}$ (but we consider the limiting case $\mu \rightarrow \bar{\beta}$).

For the analysis that follows, it is convenient to define

$$\hat{\mu} \equiv \bar{\beta} \left[ 1 + \frac{(1 - \alpha \theta)(1 - \bar{\beta} \delta)(\bar{\varepsilon} - \varepsilon)}{\bar{\varepsilon}} \right] \quad \text{and} \quad \bar{\mu} \equiv \bar{\beta} \left[ 1 + \frac{\alpha \theta(1 - \bar{\beta} \delta)(\bar{\varepsilon} - \varepsilon_L)}{\bar{\beta} \delta \bar{\varepsilon} + (1 - \bar{\beta} \delta) \varepsilon_L} \right]$$

(10)

where $\bar{\varepsilon} \in [\varepsilon, \varepsilon_H]$ is the unique solution to

$$\bar{\varepsilon} - \varepsilon + \alpha \theta \int_{\varepsilon_L}^{\bar{\varepsilon}} (\bar{\varepsilon} - \varepsilon) dG(\varepsilon) = 0.$$  

(11)

Lemma 4 (in the appendix) establishes that $\hat{\mu} < \bar{\mu}$. The following proposition summarizes the equilibrium set.

**Proposition 2** (i) A nonmonetary equilibrium exists for any parametrization. (ii) There is no stationary monetary equilibrium if $\mu \geq \bar{\mu}$. (iii) In the nonmonetary equilibrium, $A_t^* = A^* - A_{Dt}^s = A^*$ (only investors hold equity shares), there is no trade in the OTC market, and the equity price in the Walrasian market is

$$\phi_t^s = \phi^s y_t, \text{ with } \phi^s = \frac{\bar{\beta} \delta}{1 - \bar{\beta} \delta} \bar{\varepsilon}. $$

(12)
(iv) If \( \mu \in (\bar{\beta}, \bar{\mu}) \), then there is one stationary monetary equilibrium; asset holdings of dealers and investors at the beginning of the OTC round of period \( t \) are 
\[
A^m_{Dt} = A^m_t - A^m_{It} = 0
\]
and asset prices are
\[
\phi^s = \phi^s y_t, \quad \text{with } \phi^s = \begin{cases} 
\frac{\bar{\beta}}{1-\beta} \varepsilon^s & \text{if } \bar{\beta} < \mu < \bar{\mu} \\
\varepsilon^s + \alpha \theta \int_{\varepsilon_L}^{\varepsilon^s} (\varepsilon^s - \varepsilon) \, dG(\varepsilon) & \text{if } \mu = \bar{\mu} \\
0 & \text{if } \bar{\mu} < \mu < \bar{\mu}
\end{cases}
\]
and
\[
\phi^m_t = \phi^s A^m_t
\]
and
\[
p_t = \frac{\phi^s}{Z} A^m_t
\]
where
\[
Z = \frac{\alpha G(\varepsilon^s) A^s_t + A^s_{Dt} (\varepsilon^s + \phi^s)}{\alpha [1 - G(\varepsilon^s)]}
\]
and for any \( \mu \in (\bar{\beta}, \bar{\mu}) \), \( \varepsilon^s \in (\varepsilon_L, \varepsilon_H) \) is the unique solution to
\[
\frac{(1 - \bar{\beta}) \int_{\varepsilon_L}^{\varepsilon^s} (\varepsilon - \varepsilon^s) \, dG(\varepsilon)}{\varepsilon^s + \varepsilon^s + \alpha \theta \int_{\varepsilon_L}^{\varepsilon^s} (\varepsilon^s - \varepsilon) \, dG(\varepsilon)} - \frac{\mu - \bar{\beta}}{\bar{\beta} \alpha \theta} = 0.
\]

(v) (a) As \( \mu \to \bar{\mu} \), \( \varepsilon^s \to \varepsilon_L \) and \( \phi^s \to \frac{\bar{\beta}}{1-\beta} \varepsilon y_t \). (b) As \( \mu \to \bar{\beta} \), \( \varepsilon^s \to \varepsilon_H \) and \( \phi^s \to \frac{\bar{\beta}}{1-\beta} \varepsilon y_t \).

In the nonmonetary equilibrium, dealers are inactive and equity shares are held only by investors. With no valued money, investors and dealers cannot exploit the gains from trade that arise from the heterogeneity in valuation types in the first subperiod of every period, and the equilibrium real asset price, \( \phi^s = \frac{\bar{\beta}}{1-\beta} \varepsilon y_t \), is equal to the expected discounted value of the dividend stream since the equity share is not traded. (Shares can be traded in the Walrasian market of the second subperiod, but gains from trade at that stage are nil.) The stationary monetary equilibrium exists only if the inflation rate is not too high, i.e., if \( \mu < \bar{\mu} \). In the monetary equilibrium, the marginal valuation type, \( \varepsilon^s \), which according to Lemma 1 partitions the set of investors into those who buy and those who sell the asset when they meet a dealer in the OTC market, is characterized in part (iv) of Proposition 2. Unlike what happens in the nonmonetary equilibrium, the OTC market is active in the monetary equilibrium, and it is easy
to show that the marginal type, $\varepsilon^*$, is strictly decreasing in the rate of inflation, i.e., $\frac{d\varepsilon^*}{d\mu} < 0$ for $\mu \in (\tilde{\beta}, \hat{\mu})$ and for $\mu \in (\hat{\mu}, \bar{\mu})$ (see Corollary 3 in the appendix). Intuitively, the real value of money falls as $\mu$ increases, so the marginal investor type, $\varepsilon^*$, decreases, reflecting the fact that under the higher inflation rate, the investor that was marginal under the lower inflation rate is no longer indifferent between carrying cash and equity out of the OTC market—he prefers equity.

According to Proposition 2, $0 \leq \varepsilon_L < \varepsilon^*_t$ in the monetary equilibrium, so Lemma 1 implies that dealers hold no equity shares at the end of the OTC round: all equity is held by investors, in particular, by those investors who carried equity into the period but were unable to contact a dealer, and by those investors who purchased equity shares in bilateral trades with dealers. After the round of OTC trade, all the money supply is held by the investors who carried cash into the period but were unable to contact a dealer, by the investors who sold equity shares through dealers, and by those dealers who carried equity into the OTC market.

A feature of the monetary equilibrium is that dealers never hold money overnight: at the beginning of every period $t$, the money supply is all in the hands of investors, i.e., $A^m_{Dt} = 0$ and $A^m_{It} = A^m_t$. The reason is that access to the interdealer market allows dealers to intermediate assets without having to use cash. Whether it is investors or dealers who hold the equity overnight, depends on the inflation rate: if it is low, i.e., if $\mu \in (\tilde{\beta}, \hat{\mu})$, then only dealers hold equity shares overnight, that is, $\hat{A}^s_{Dt+1} = A^s$ and $\hat{A}^s_{It+1} = 0$ for all $t$. Conversely, if the inflation rate is high, i.e., if $\mu \in (\hat{\mu}, \bar{\mu})$, then at the end of every period $t$, all equity shares are in the hands of investors, i.e., $\hat{A}^s_{Dt+1} = 0$ and $\hat{A}^s_{It+1} = A^s$ so strictly speaking, in this case dealers only provide brokerage services in the OTC market. The intuition for this result is as follows. For dealers, the return from holding equity overnight is given by the resale price in the OTC market. If inflation is low, $\varepsilon^*_t$ is high (the asset is being priced by relatively high valuation investors) and this means the resale price in the OTC market is high. Since dealers are sure to trade in the OTC market every period while investors only trade with effective probability $\alpha \theta$, the former are in a better position to reap the capital gains and end up holding all equity shares overnight. Conversely if inflation is high then $\varepsilon^*_t$ is low so the capital gain to a dealer from carrying the asset to sell in the OTC market is small. The gain to investors includes not only the resale value in the OTC market (which is small at high inflation) but also their own expected valuation of the dividend good, so for high inflation investors obtain a higher

---

4See Lagos and Zhang (2015) for a more detailed discussion.
return from holding equity overnight than dealers. For example, as \( \mu \to \bar{\mu} \) we have \( \varepsilon^* \to \varepsilon_L \), so the dealer’s expected return from holding equity overnight is \( \frac{(\varepsilon_L + \phi^*)y}{\phi} \), while the investor’s is \( \frac{(\varepsilon + \phi^*)y}{\phi} \).

Given the marginal valuation type, \( \varepsilon^* \), part (iv) of Proposition 2 gives all asset prices in closed form. The real price of equity (in terms of the homogeneous consumption good) in the Walrasian round of trade, \( \phi_t^e \), is given by (18). The dollar price of equity in the OTC market, \( p_t \), is given by (16). The real price of money (in terms of the homogeneous consumption good) in the Walrasian round of trade, \( \phi_t^m \), is given by (15). The real price of equity (in terms of the homogeneous consumption good) in the OTC market, \( p_t \phi_t^m = \bar{\phi}^s y_t \) is given by (14).

Finally, part (v)(a) states that as the rate of money creation rises toward \( \bar{\mu} \), \( \varepsilon^* \) approaches the lower bound of the type distribution, \( \varepsilon_L \), so no investor wishes to sell equity in the OTC market, and as a result the allocations and prices of the monetary equilibrium approach those of the nonmonetary equilibrium. Part (v)(b) states that as \( \mu \) decreases toward \( \bar{\beta} \), \( \varepsilon^* \) increases toward the upper bound of the type distribution, \( \varepsilon_H \), so only investors with the highest valuation type purchase equity in the OTC market (all other investors wish to sell it). Moreover, since \( \bar{\beta} < \bar{\mu} \), as \( \mu \to \bar{\beta} \) only dealers hold equity overnight. Thus we have the following result.

**Corollary 1** The allocation implemented by the stationary monetary equilibrium converges to the efficient allocation as \( \mu \to \bar{\beta} \).

Let \( q_{t,k}^B \) denote the nominal price in the second subperiod of period \( t \) of an \( N \)-period risk-free pure-discount nominal bond that matures in period \( t+k \), for \( k = 0, 1, 2, ..., N \) (so \( k \) is the number of periods until the bond matures). Assume the bond is illiquid in the sense that it cannot be traded in the OTC market. Then in a stationary monetary equilibrium, \( q_{t,k}^B = (\bar{\beta}/\mu)^k \), and

\[
t = \frac{\mu}{\bar{\beta}} - 1
\]

is the time-\( t \) nominal yield to maturity of the bond with \( k \) periods until maturity. Thus, the optimal monetary policy described in Corollary 1 and part (v)(b) of Proposition 2 in which the money supply grows at rate \( \bar{\beta} \), can be interpreted as a policy that implements the Friedman rule, i.e., \( t = 0 \) for all contingencies at all dates.

**Example 1** Suppose that the probability distribution over investor valuations is concentrated on two points: \( \varepsilon_L \) with probability \( \pi_L \) and \( \varepsilon_H \) with probability \( \pi_H \), with \( \bar{\varepsilon} = \pi_H \varepsilon_H + \pi_L \varepsilon_L \). Then
(18) reduces to

\[ \epsilon^* = \begin{cases} \frac{\epsilon_H}{\mu - \beta} & \text{if } \bar{\beta} < \mu \leq \hat{\mu} \\ \frac{\bar{\alpha}\theta(1 - \beta \delta)\pi_H\epsilon_H - (\mu - \bar{\beta})\beta\delta(\epsilon - \alpha\theta\pi_L\epsilon_L)}{\bar{\beta}\theta(1 - \beta \delta)\pi_H + (\mu - \bar{\beta})(1 - \beta \delta)(1 - \alpha\theta\pi_L)} & \text{if } \hat{\mu} < \mu < \bar{\mu} \end{cases} \]

with

\[ \hat{\mu} = \bar{\beta} \left[ 1 + \frac{(1 - \bar{\beta} \delta)(1 - \alpha\theta)\alpha\theta\pi_L(\bar{\epsilon} - \epsilon_L)}{\bar{\epsilon} - \alpha\theta\pi_L\epsilon_L} \right] \quad \text{and} \quad \bar{\mu} = \bar{\beta} \left[ 1 + \frac{(1 - \bar{\beta} \delta)\alpha\theta(\bar{\epsilon} - \epsilon_L)}{\beta\delta\bar{\epsilon} + (1 - \beta \delta)\epsilon_L} \right]. \]

Given \( \epsilon^* \), the rest of the equilibrium allocation is given in Proposition 2.

5 Implications

In this section we discuss the main implications of the theory. Specifically, we show how asset prices and conventional measures of financial liquidity (spreads, trade volume, and dealer supply of immediacy) are determined by the quantity of money (the inflation regime) and the details of the microstructure where the asset trades (e.g., the degree of market power of dealers and the ease with which investors find counterparties). We also show that generically, asset prices in the monetary economy exhibit a speculative premium (or speculative “bubble”) whose size varies systematically with the inflation regime and the market microstructure.

5.1 Asset prices

In this subsection we study the asset pricing implications of the theory. We focus on how the asset price depends on monetary policy and on the degree of OTC frictions as captured by the parameters that regulate trading frequency and the relative bargaining strengths of the various traders.

5.1.1 Inflation

The real price of equity in a monetary equilibrium is in part determined by the option available to low-valuation investors to resell the equity to high-valuation investors. As the nominal rate \( \iota \) (or equivalently, the inflation rate \( \mu \)) increases, equilibrium real money balances decline and the marginal investor type, \( \epsilon^* \), decreases reflecting the fact that under the higher nominal rate, the investor type that was marginal under the lower nominal rate is no longer indifferent between carrying cash and equity out of the OTC market (he prefers equity). Since the marginal investor...
who prices the equity in the OTC market has a lower valuation, the value of the resale option is smaller, i.e., the turnover liquidity of the asset is lower, which in turn makes the real equity price (both $\phi^s$ and $\tilde{\phi}^s$) smaller. Naturally, the real value of money, $\phi^m_t$, is also decreasing in the nominal interest rate. All this is formalized in Proposition 3. The top row of Figure ?? illustrates the typical time paths of the ex-dividend equity price, $\phi^s_t$, real balances, $\phi^m_t A^m_t$, and the price level, $\phi^m_t$, for different values of $\mu$.

**Proposition 3** In the stationary monetary equilibrium: 
(i) $\partial \phi^s / \partial \mu < 0$ and $\partial \phi^s / \partial \ell < 0$, (ii) $\partial \tilde{\phi}^s / \partial \mu < 0$, (iii) $\partial Z / \partial \mu < 0$ and $\partial \phi^m / \partial \mu < 0$.

### 5.1.2 OTC frictions: trading delays and market power

In the OTC market, $\alpha \theta$ is an investor’s effective bargaining power in negotiations with dealers. A larger $\alpha \theta$ implies a larger gain from trade for low-valuation investors when they sell the asset to dealers. In turn, this makes investors more willing to hold equity shares in the previous period, since they anticipate larger gains from selling the equity in case they were to draw a relatively low valuation type in the following OTC round. Hence real equity prices, $\phi^s$ and $\tilde{\phi}^s$, are increasing in $\alpha$ and $\theta$. If $\alpha$ increases, money becomes more valuable (both $Z$ and $\phi^m_t$ increase), provided we focus on a regime in which only investors carry equity overnight. Proposition 4 formalizes these ideas. The bottom row of Figure ?? illustrates the time paths of the ex-dividend equity price, $\phi^s_t$, real balances $\phi^m_t A^m_t$, and the price level, $\phi^m_t$ for two different values of $\alpha$.

**Proposition 4** In the stationary monetary equilibrium: 
(i) $\partial \phi^s / \partial (\alpha \theta) > 0$, (ii) $\partial \tilde{\phi}^s / \partial (\alpha \theta) > 0$, (iii) $\partial Z / \partial \alpha > 0$ and $\partial \phi^m / \partial \alpha > 0$, for $\mu \in (\hat{\mu}, \tilde{\mu})$.

### 5.2 Financial liquidity

In this subsection we use the theory to study the determinants of standard measures of market liquidity: liquidity provision by dealers, trade volume, and bid-ask spreads.

---

5 This finding is consistent with the behavior of the illiquidity premia in response to variations in the measures of liquidity documented by Ang et al. (2013).

6 Real balances can actually fall with $\alpha$ for $\mu \in (\tilde{\beta}, \hat{\mu})$. 
5.2.1 Liquidity provision by dealers

Broker-dealers in financial markets provide liquidity (immediacy) to investors by finding them counterparties for trade, and/or by trading with them out of their own account, effectively becoming their counterparty. The following result characterizes the effect of inflation on dealers’ provision of liquidity by accumulating assets.

**Proposition 5** In the stationary monetary equilibrium: (i) dealers’ provision of liquidity by accumulating assets, i.e., $A^s_D$, is nonincreasing in the inflation rate. (ii) For any $\mu$ close to $\bar{\beta}$, dealers’ provision of liquidity by accumulating assets is nonmonotonic in $\alpha\theta$, i.e., $A^s_D = 0$ for $\alpha\theta$ close to 0 and close to 1, but $A^s_D > 0$ for intermediate values of $\alpha\theta$.

To understand part (i) of Proposition 5, recall the discussion that followed Proposition 2. The expected return from holding equity is larger for investors than for dealers with high inflation ($\mu > \hat{\mu}$) because in that case the expected resale value of equity in the OTC market is relatively low, and dealers only buy equity to resell in the OTC market, while investors also buy it with the expectation of getting utility from the dividend flow. For low inflation ($\mu < \hat{\mu}$), dealers value equity more than investors because the OTC resale value is high and they have a higher probability of making capital gains from reselling than investors, and this trading advantage more than compensates for the fact that investors enjoy the additional utility from the dividend flow. Part (ii) of Proposition 5 states that given a low enough rate of inflation, dealers’ incentives to hold equity inventories overnight depend nonmonotonically on the degree of OTC frictions as measured by $\alpha\theta$. In particular, dealers will not hold inventories if $\alpha\theta$ is either very small or very large. If $\alpha\theta$ is close to zero, few investors contact the interdealer market, and this makes the equity price in the OTC market very low, which in turn implies too small a capital gain to induce dealers to hold equity overnight. Conversely, if $\alpha\theta$ is close to one, a dealer has no trading advantage over an investor in the OTC market and since the investor gets utility from the dividend while the dealer does not, the investor has a higher willingness to pay for the asset in the centralized market than the dealer, and therefore it is investors and not dealers who carry the asset overnight into the OTC market.

5.2.2 Trade volume

Trade volume is commonly used as a measure of market liquidity because it is a manifestation of the ability of the market to reallocate assets across investors. According to Lemma 1, any
investor with $\varepsilon < \varepsilon^*_t$ who has a trading opportunity in the OTC market, sells all his equity holding. Hence in a stationary equilibrium, the quantity of assets sold by investors to dealers in the OTC market is $Q^s = \alpha G(\varepsilon^*) A_T^I$. From Lemma 1, the quantity of assets purchased by investors from dealers is $Q^b = \alpha [1 - G(\varepsilon^*)] A_T^m / p_t$. Thus the total quantity of equity shares traded in the OTC market is $V = Q^b + Q^s$, or equivalently$^7$

$$V = 2\alpha G(\varepsilon^*) A_T^I + A_T^D. \tag{20}$$

Trade volume, $V$, depends on the nominal rate $\iota$ (or equivalently, inflation $\mu$) and dealers’ market power $\theta$ indirectly, through $\varepsilon^*$. A decrease in $\iota$ or an increase in $\theta$, increases the expected return to holding money, which makes more investors willing to sell equity for money in the OTC market, i.e., $\varepsilon^*$ increases and so does trade volume. In other words, the increase in turnover liquidity caused by the increase in $\iota$ or $\theta$ manifests itself through an increase in trade volume. The indirect positive effect on $V$ (through $\varepsilon^*$) of an increase in the investors’ trade probability $\alpha$ is similar to an increase in $\theta$, but in addition, $\alpha$ directly increases trade volume since with a higher $\alpha$ more investors are able to trade in the OTC market. These results are summarized in the following proposition.

**Proposition 6** In the stationary monetary equilibrium: (i) $\partial V / \partial \mu < 0$ and $\partial V / \partial \iota < 0$, and (ii) $\partial V / \partial \theta > 0$ and $\partial V / \partial \alpha > 0$.

### 5.2.3 Bid-ask spreads

Bid-ask spreads and intermediation fees are a popular measure of market liquidity as they constitute the main out-of-pocket transaction cost that investors bear in OTC markets. Lemma 1 shows that when dealers execute trades on behalf of their investors, they charge a fee $k_t(a_t, \varepsilon)$ that is linear in the trade size. This means that when an investor with $\varepsilon > \varepsilon^*_t$ wants to buy equity, the dealer charges him an ask price, $p^a_t(\varepsilon) = p_t \phi^m_t + (1 - \theta) (\varepsilon - \varepsilon^*_t) y_t$ per share.

When an investor with $\varepsilon < \varepsilon^*_t$ wants to sell, the dealer pays him a bid price, $p^b_t(\varepsilon) = p_t \phi^m_t - (1 - \theta) (\varepsilon^*_t - \varepsilon) y_t$ per share. Define $S^a_t(\varepsilon) = \frac{p^a_t(\varepsilon) - p_t \phi^m_t}{p_t \phi^m_t}$ and $S^b_t(\varepsilon) = \frac{p_t \phi^m_t - p^b_t(\varepsilon)}{p_t \phi^m_t}$, i.e., the ask spread and bid spread, respectively, expressed as fractions of the price of the asset in the interdealer market. Then in a stationary equilibrium, the ask spread earned by a dealer when

---

$^7$To obtain (20) we used the clearing condition for the interdealer market, $Q^b = Q^s + A_D^I$. Also, note that $V$ is trade volume in the OTC market, but since every equity share traded in the first subperiod gets retracted in the second subperiod, total trade volume in the whole time period equals $2V$. 

18
trading with an investor with $\varepsilon > \varepsilon^*$ is
\[ S^a(\varepsilon) = \frac{(1 - \theta)(\varepsilon - \varepsilon^*)}{\varepsilon^* + \phi^s} \]
and the bid spread earned by a dealer when trading with an investor with $\varepsilon < \varepsilon^*$ is
\[ S^b(\varepsilon) = \frac{(1 - \theta)(\varepsilon^* - \varepsilon)}{\varepsilon^* + \phi^s} \]
The average real spread earned by dealers is
\[ \bar{S} = \int [S^a(\varepsilon) I\{\varepsilon < \varepsilon^*\} + S^b(\varepsilon) I\{\varepsilon < \varepsilon^*\}] \ dG(\varepsilon). \]
The change $\bar{S}$ in response to changes in $\mu$ or $\alpha$ is ambiguous in general.\(^8\)

5.3 Speculative premium

According to Proposition 2, in a monetary equilibrium the equity price, $\phi^s$, is larger than the expected present discounted value that any agent assigns to the dividend stream, i.e., $\hat{\phi}_t \equiv \left[ \hat{\beta} \delta / (1 - \hat{\beta} \delta) \right] \bar{G}_t y_t$. We follow Harrison and Kreps (1978) and call the value of the asset in excess of the expected present discounted value of the dividend, i.e., $\phi^s_t - \hat{\phi}_t$, the speculative premium that investors are willing to pay in anticipation of the capital gains they will reap when reselling the asset to investors with higher valuations in the future.\(^9\) Like Harrison and Kreps (1978), we say that investors exhibit speculative behavior if the right to resell a stock makes them willing to pay more for the stock than if they were obliged to hold it forever. Investors exhibit speculative behavior in the sense that they buy with the expectation to resell, and naturally the asset price incorporates the value of this option to resell.

The speculative premium in a monetary equilibrium is $\mathcal{P}_t = \mathcal{P} y_t$, where
\[ \mathcal{P} = \begin{cases} \frac{\bar{G}_t}{1 - \bar{G}_t} (\varepsilon^* - \bar{\varepsilon}) & \text{if } \bar{\beta} < \mu \leq \hat{\mu} \\ \frac{\bar{G}_t}{1 - \bar{G}_t} \alpha \theta \int_{\varepsilon^*}^{\varepsilon^*} G(\varepsilon) \ d\varepsilon & \text{if } \hat{\mu} < \mu < \hat{\mu}. \end{cases} \]

\(^8\)The reason is that the spread $S^a(\varepsilon)$ charged to buyers is decreasing in $\varepsilon^*$ while the spread $S^b(\varepsilon)$ charged to sellers may be increasing in $\varepsilon^*$. For example, if $\mu \in (\bar{\beta}, \hat{\beta})$, it is easy to show $\partial S^a(\varepsilon)/\partial \varepsilon^* = -\partial S^b(\varepsilon)/\partial \varepsilon^* < 0$.

\(^9\)It is commonplace to define the fundamental value of the asset to be the expected present discounted value of the dividend stream, and to call any transaction value in excess of this benchmark, a bubble. In fact, our notion of speculative premium corresponds to the notion of speculative bubble that is used in the modern literature on bubbles. See, e.g., Barlevy (2007), Brunnermeier (2003), Scheinkman and Xiong (2003a,b), Scheinkman (2013), and Xiong (2013), who discuss Harrison and Kreps (1978) in the context of what is generally known as the resale-option theory of bubbles. One could argue, of course, that the relevant notion of “fundamental value” should be calculated through market aggregation of diverse investor valuations and taking into account the monetary policy stance as well as all the details of the market structure in which the asset is traded (such as the frequency of trading opportunities and the degree of market power of financial intermediaries), which ultimately also factor into the asset price in equilibrium. We adopt the label used by Harrison and Kreps (1978) to avoid semantic controversies.
The speculative premium is positive in any monetary equilibrium, i.e., $P_t \geq 0$, with “=” only if $\mu = \bar{\mu}$. Since $\partial \varepsilon^*/\partial \mu < 0$ (Corollary 3), it is immediate that the speculative premium is decreasing in the rate of inflation. Intuitively, anticipated inflation reduces the real money balances used to finance asset trading, which limits the ability of high-valuation traders to purchase the asset from low-valuation traders. As a result, the speculative premium is decreasing in $\mu$. Since $\partial \varepsilon^*/\partial (\alpha \theta) > 0$ (see the proof of Proposition 4), the speculative premium is increasing in $\alpha$ and $\theta$. Intuitively, the speculative premium is the value of the option to resell the equity to a higher valuation investor in the future, and the value of this resale option to the investor increases with the probability $\alpha$ that the investor gets a trading opportunity in an OTC trading round and with the probability $\theta$ that he can capture the gains from trade in those trades. So in low-inflation regimes, the model predicts large trade volume and a large speculative premium. The following proposition summarizes these results.

**Proposition 7** In the stationary monetary equilibrium: (i) $\partial P/\partial \mu < 0$ and $\partial P/\partial \iota < 0$, and (ii) $\partial P/\partial (\alpha \theta) > 0$.

Together, Proposition 6 and Proposition 7 imply that changes in the trading probability will generate a positive correlation between trade volume and the size of the speculative premium. The positive correlation between trade volume and the size of the speculative premium is a feature of historical episodes that are usually regarded as bubbles—a point emphasized by Scheinkman and Xiong (2003a, 2003b) and Scheinkman (2013).

### 6 Empirical results

According to the theory, the real asset price decreases in response to an entirely unanticipated and permanent increase in the nominal interest rate (part (i) of Proposition 3). The mechanism through which the increase in the nominal rate is transmitted to the asset price is the reduction in turnover liquidity evidenced in the reduction in trade volume (part (i) of Proposition 6). These two theoretical results suggest two hypotheses that can be tested with asset pricing and turnover data: (a) surprise increases in the nominal rate reduce real stock returns, and (b) the mechanism operates through a reduction in turnover liquidity (e.g., as measured by trade volume).
6.1 Data

We use daily time series for all individual common stocks in the New York Stock Exchange (NYSE) from the Center for Research in Security Prices (CRSP). The daily stock return from CRSP takes into account changes in prices and accrued dividend payment, i.e., the return of stock $s$ on day $t$ is $R_s^t = \left( \frac{P_s^t + D_s^t}{P_{s, t-1}} - 1 \right) \times 100$, where $P_s^t$ is the ex-dividend dollar price of stock $s$ on day $t$ and $D_s^t$ denotes the dollar dividend paid per share of stock $s$ on day $t$. As a measure of trade volume for each stock, we construct the daily turnover rate from CRSP, i.e., $T_s^t = \frac{V_s^t}{A_s^t}$, where $V_s^t$ is the trade volume of stock $s$ on day $t$ (measured as the total number of shares traded) and $A_s^t$ is the number of outstanding shares of stock $s$ on day $t$. Whenever we use an average, e.g., of equity returns or turnover rates across a set of stocks, we use the arithmetic average, e.g., $R_I^t = \frac{1}{n} \sum_{s=1}^{n} R_s^t$ and $T_I^t = \frac{1}{n} \sum_{s=1}^{n} T_s^t$ are the average return and the average turnover rate for the universe of $n$ common stocks listed in the NYSE.

The changes in the short-term nominal interest used in the empirical analysis are for the rate on the nearest Eurodollar futures contract to expire after the FOMC (Federal Open Market Committee) policy announcement, as in Rigobon and Sack (2004). Specifically, we use the 3-Month Eurodollar futures rate produced by the CME Group (Chicago Mercantile Exchange Group) and supplied by Datastream.

Some of our estimations require us to divide the sample into two subsamples: one of the data for the FOMC policy announcement days, and another of the data for the trading days immediately before the policy announcement days. In what follows we refer to these subsamples as $S_1$ and $S_0$, respectively. The sample we analyze runs from January 3, 1994 to November 26, 2001. Prior to 1994 policy changes in the fed funds target were unannounced and frequently occurred between FOMC meetings. From 1994, all changes are announced and most coincided with FOMC meetings, so as policy announcement dates we use the dates of FOMC meetings

---

10Eurodollar futures are based on a $1 million face value 3-month maturity Eurodollar Time Deposit. These futures contracts mature during the months of March, June, September, or December, extending outward 10 years into the future. An advantage of using this interest rate as the “policy rate” is that its movement on dates of FOMC policy announcements reflects only policy surprises. The importance of focusing on the surprise component of policy announcements (rather than the anticipated component) in order to identify the response of asset prices to monetary policy was originally pointed out by Kuttner (2001) and has been emphasized by the literature since then, e.g., Bernanke and Kuttner (2005), Rigobon and Sack (2004). One drawback of using futures contracts is that because they expire quarterly, depending on the timing of the FOMC announcement, the nearest contract to expire may expire between zero and three months after the announcement. Gürkaynak et al. (2007) offer empirical evidence supporting the use of futures contracts as an effective proxy for policy expectations and discuss their use to define policy shocks.

11In the appendix we extend the sample period through 2007.
obtained from the website of the Board of Governors of the Federal Reserve System.\footnote{The web address is http://www.federalreserve.gov/monetarypolicy/fomccalendars.htm. See Bernanke and Kuttner (2005) for more discussion on the exact timing of policy announcements.} The sample we use includes between 1300 and 1800 stocks (depending on the time period) and 73 policy dates.\footnote{Our full sample contains 78 policy dates but we follow Rigobon and Sack (2004) and discard five of these policy dates because they are preceded by either one or two holidays in financial markets. Those observations are needed because one of our procedures requires data involving first differences in variables on the policy day and on the day preceding the policy day.}

In the following subsections we use the data described above to estimate the effects of monetary policy on stock returns and turnover. In Subsection 6.2 we estimate these effects for the policy announcement day on which the policy surprise takes place for a broad set of stocks. In Subsection 6.3 we document that the strength of the effect of monetary policy on stock returns differs systematically with the turnover liquidity of the stock. In Subsection 6.4 we go a step further and estimate the dynamic effects of the policy announcement on returns and turnover.

### 6.2 Aggregate announcement-day effects

The empirical literature has followed two approaches to estimate the impact of monetary policy surprises on the stock market on the day of a policy announcement. The first, known as “event-study analysis,” consists of estimating the market reaction to monetary policy surprises on a sample consisting exclusively of the days of monetary policy announcements. Let $i_t$ denote the day-$t$ “policy rate” (in our case the CME Group 3-Month Eurodollar future with closest expiration date at or after day $t$, expressed in percentage terms) and define $\Delta i_t = i_t - i_{t-1}$.

The event-study analysis consists of running the following regression

$$ R^I_t = a + b \Delta i_t + \epsilon_t \tag{21} $$

for $t \in S_1$, where $\epsilon_t$ is an exogenous shock to the asset price.\footnote{In the context of monetary policy, this approach was originally used by Cook and Hahn (1989) and has been followed by a large number of papers, e.g., Bernanke and Kuttner (2005), Cochrane and Piazzesi (2002), Kuttner (2001), Thorbecke (1997).} We refer to the estimator $b$ as the event-study estimator (or “E-study” estimator, for short).

A concern with (21) is it does not take into account the fact that the policy rate on the right side may itself be reacting to asset prices (a simultaneity bias) and that a number of other variables (e.g., news about economic outlook) are likely to impact both the policy rate and
asset prices (an omitted variables bias). In this context, this concern has motivated another estimation approach proposed by Rigobon and Sack (2004). They show that the response of asset prices to changes in monetary policy can be identified based on the increase in the variance of policy shocks that occurs on days of FOMC announcements, and they argue that this approach tends to be more reliable than the event-study approach because identification relies on a weaker set of conditions.

The key idea behind the heteroskedasticity-based estimator of Rigobon and Sack (2004) is as follows. Suppose the change in the policy rate, $\Delta i_t$, and the stock-market return, $R^I_t$, are jointly determined by

$$\Delta i_t = \kappa R^I_t + \varpi x_t + \epsilon_t$$  \hspace{1cm} (22) \\
$$R^I_t = \rho \Delta i_t + x_t + \eta_t$$  \hspace{1cm} (23) 

where $\epsilon_t$ is a monetary policy shock and $\eta_t$ is a shock to the asset price. Equation (22) represents the monetary policy reaction to asset returns and possibly other variables represented by $x_t$. Equation (23) represents the reaction of asset prices to the policy rate and $x_t$. The disturbances $\epsilon_t$ and $\eta_t$ are assumed to have no serial correlation and to be uncorrelated with each other and with $x_t$. We are interested in estimating the parameter $\rho$. Let $\Sigma_y$ denote the variance of some variable $y$. If (22) and (23) were the true model and one were to run an OLS regression on an equation like (21), there would be a simultaneity bias if $\kappa \neq 0$ and $\Sigma_\eta > 0$, and an omitted variable bias if $\varpi \neq 0$ and $\Sigma_x > 0$. Conditions (22) and (23) can be solved for

$$\Delta i_t = \frac{1}{1-\rho \kappa} [\kappa \epsilon_t + \kappa \eta_t + (\kappa + \varpi) x_t]$$  \\
$$R^I_t = \frac{1}{1-\rho \kappa} [\rho \epsilon_t + \eta_t + (1 + \rho \varpi) x_t].$$

Let $\Omega^k$ denote the covariance matrix of $\Delta i_t$ and $R^I_t$ for $t \in S_k$, for $k \in \{0, 1\}$. Then

$$\Omega^k = \frac{1}{(1-\rho \kappa)^2} \begin{bmatrix} \Omega_{11}^k & \Omega_{12}^k \\ \Omega_{21}^k & \Omega_{22}^k \end{bmatrix}$$

where $\Omega_{11}^k = \Sigma_{\epsilon}^k + \kappa^2 \Sigma_{\eta}^k + (\kappa + \varpi)^2 \Sigma_x^k$, $\Omega_{12}^k = \Omega_{21}^k = \rho \Sigma_{\epsilon}^k + \kappa \Sigma_{\eta}^k + (\kappa + \varpi) (1 + \rho \varpi) \Sigma_x^k$, $\Omega_{22}^k = \rho^2 \Sigma_{\epsilon}^k + \Sigma_{\eta}^k + (1 + \rho \varpi)^2 \Sigma_x^k$, and $\Sigma_x^k$ denotes the variance of variable $x$ in subsample $S_k$, for $k \in \{0, 1\}$. Provided $\Sigma_x^0 = \Sigma_x^1$ and $\Sigma_{\eta}^0 = \Sigma_{\eta}^1$,

$$\Omega^1 - \Omega^0 = \frac{\Sigma^1 - \Sigma^0}{(1-\rho \kappa)^2} \begin{bmatrix} 1 & \rho \\ \rho & \rho^2 \end{bmatrix}.$$ 

Hence if $\Sigma^1 - \Sigma^0 > 0$, then $\rho$ can be identified from the difference in the covariance matrices of the two subsamples. This suggests a natural way to estimate $\rho$. Replace $\Omega^1$ and $\Omega^0$ with their
sample estimates, denoted $\hat{\Omega}^1$ and $\hat{\Omega}^0$. Define $\hat{\Omega} \equiv \hat{\Omega}^1 - \hat{\Omega}^0$ and use $\hat{\Omega}_{ij}$ to denote the $(i,j)$ element of $\hat{\Omega}$. Then $\rho$ can be estimated by $\hat{\rho} \equiv \hat{\Omega}_{12}/\hat{\Omega}_{11}$. Rigobon and Sack (2004) show that this estimate can be obtained by regressing $R^I_t$ on $\Delta i_t$ over the combined sample $S_0 \cup S_1$ using a standard instrumental variables regression. We refer to the estimator obtained following this procedure as the heteroskedasticity-based estimator (“H-based” for short).

The standard deviation of $\Delta i_t$ is 3.53 basis points (bps) in subsample $S_0$ and 6.84 bps in subsample $S_1$. The standard deviation of $R^I_t$ is 49.67 bps in subsample $S_0$ and 64.22 bps in subsample $S_1$. The correlation between $\Delta i_t$ and $R^I_t$ is 0.19 in subsample $S_0$ and $-0.4$ in subsample $S_1$. Stock returns are more volatile on the days of monetary policy announcements than on other days, which is consistent with policy actions inducing some reaction in the stock market. The relatively large negative correlation between the policy rate and stock returns for announcement days contrasts with the much smaller and positive correlation for non-announcement days, suggesting the negative effect of surprise increases in the nominal rate on stock prices that has been documented in the empirical literature (e.g., Bernanke and Kuttner, 2005, Rigobon and Sack, 2004).

Table 1 presents the baseline results. The first column corresponds to the event-based estimation and the second column to the heteroskedasticity-based estimation. All variables are expressed in percentage terms. The first row presents estimates of the reaction of equity returns to monetary policy. The point estimate for $b$ in (21) is $-3.77$. This means that a 1 percentage point (pp) increase in the policy rate causes a decrease of 3.77 percentage points (pps) in the stock market return on the day of the policy announcement. The point estimate for $\rho$ in (23) is $-6.18$, implying a 25 bp increase in the policy rate causes a decrease in the stock market return of 1.54 pps on the day of the policy announcement. These results are in line with those reported in previous studies.

Previous studies, however, have not identified the specific economic mechanism that transmits monetary policy shocks to the stock market. Conventional asset pricing theory suggests three broad immediate reasons why an unexpected policy rate increase may lead to a decline

\footnote{The $R^2$ indicates that 16 percent of the variance of equity prices in days of FOMC policy announcements is associated with news about monetary policy.}

\footnote{The comparable event-based estimates in Bernanke and Kuttner (2005), who focus on a different sample period and measure stock returns using the value-weighted return from CRSP, range between $-2.55$ percent and $-4.68$ percent. The comparable heteroskedasticity-based estimates in Rigobon and Sack (2004), who use a different series for the Eurodollar forward rate, are $-6.81$ for the S&P 500 index, $-6.5$ for the WIL5000 index, $-9.42$ for the NASDAQ, and $-4.85$ for the DJIA.}
in stock prices. It may be associated with a decrease in expected dividend growth, with a rise in the future real interest rates used to discount dividends, or with an increase in the expected excess returns (i.e., equity premia) associated with holding stocks. Our theory formalizes a new mechanism: the reduction in turnover liquidity caused by the increase in the opportunity cost of holding the nominal assets that are routinely used to settle financial transactions. To assess this theoretical mechanism, we again estimate $b$ in (21) and $\rho$ in (22)-(23), but using the daily turnover rate (averaged over all traded stocks), $T_{I_t}$, as dependent variable instead of the average stock return, $R_{I_t}$.

The mean and standard deviation of $T_{I_t}$ over the whole sample are 37.291 bps, and 8.52 bps, respectively. The standard deviation of $T_{I_t}$ is 8.03 bps in subsample $S_0$ and 8.72 bps in subsample $S_1$. The correlation between $\Delta i_t$ and $T_{I_t}$ is .06 in subsample $S_0$ and −.26 in subsample $S_1$. The negative correlation between the policy rate and the turnover rate for announcement days contrasts with the much smaller and positive correlation for non-announcement days, suggesting the negative effect of surprise increases in the nominal rate on trade volume.

The estimated effects of monetary policy announcements on the turnover rate are reported in the second row of Table 1. According to the event-based estimate, a 1 pp increase in the policy rate causes a change in the level of the market wide turnover rate on the day of the policy announcement equal to $−.0025$. The daily market wide turnover rate for our sample period is .0035 (i.e., on average stocks turn over .88 times during a typical year composed of 252 trading days), which means that an increase in the policy rate of 1 bp causes a reduction in the market wide turnover rate on the day of the policy announcement of about 0.0071 percent of its typical level. The heteroskedasticity-based estimate for a 1 pp increase in the policy rate is $−.0045$, implying that a 1 bp increase in the policy rate causes a reduction in the market wide turnover rate of about 1.3 percent of its typical level.

### 6.3 Disaggregative announcement-day effects

Another way to provide direct evidence of the turnover-liquidity transmission mechanism of monetary policy is to exploit the cross-sectional variation in turnover rates across stocks. Our theory implies that the magnitude of the change in the stock return induced by a change in the policy rate will be larger for more liquid stocks (i.e., stocks with higher turnover rate). To test
this prediction, we sort stocks into portfolios according to their turnover liquidity, as follows. For each policy announcement date, $t$, we calculate $T_{ts}$ as the average turnover rate of an individual stock $s$ over all the trading days during the four weeks prior to the day of the policy announcement. We then divide all stocks into 20 portfolios by assigning stocks with $T_{ts}$ ranked between the $[5(i - 1)]^{th}$ percentile and $(5i)^{th}$ percentile to the $i^{th}$ portfolio, for $i = 1, ..., 20$. Hence the average turnover rate over the four-week period prior to the announcement date for a stock in $i^{th}$ portfolio is at least as large as that of a stock in $(i - 1)^{th}$ portfolio. In Table 2, the column labeled “Turnover” reports the annual turnover rate (based on a year with 252 trading days) corresponding to each of the twenty portfolios. For example, portfolio 1 turns over .11 times per year while portfolio 20 turns over 3.11 times per year.\(^{18}\)

For each of the twenty portfolios, the columns in Table 2 labeled “E-based” report the event-study estimates of the responses (on the day of the policy announcement) of the return and turnover of the portfolio to a 1 pp increase in the policy rate. All the coefficients in the column labeled “Return” are negative as predicted by the theory.\(^{19}\) Also as predicted by the theory, the magnitude of the (statistically significant) coefficients increases with the turnover liquidity of the portfolio. For example, a 1 pp increase in the policy rate causes a decrease of 2.03 pps in the return of portfolio 1 and a decrease of 6.27 pps in the return of portfolio 20. Fourteen of the E-based coefficients in the column labeled “Turnover” are negative and statistically significant (at the 5% level), as predicted by the theory.\(^{20}\) Also as predicted by the theory, the magnitude of the (statistically significant) coefficients increases with the turnover liquidity of the portfolio. For example, based on the point estimates, the magnitude of the response of the turnover rate of portfolio 20 is about twelve times larger than the response of the turnover rate of portfolio 2.

In Table 2, the columns labeled “H-based” report the H-based estimates of the responses (on the day of the policy announcement) of the return and turnover of each of the twenty portfolios

\(^{18}\)Our motivation for constructing these liquidity-based portfolios is twofold. First, at a daily frequency, individual stock returns are extremely noisy. Second, stock-specific turnover measures are time-varying, i.e., the turnover rate of a particular stock may change over time. Bernanke and Kuttner (2005) also examine the responses of more disaggregated indices. Specifically, they estimate the responses to policy shocks of 10 industry portfolios constructed from CRSP returns as in Fama and French (1988) but find that the precision of their estimates is not sufficient to reject the hypothesis of an equal reaction for all 10 industries.

\(^{19}\)With the exception of those corresponding to portfolios 3 and 4, all the E-based estimates of the responses of returns reported in Table 2 are statistically significant at the 5% level.

\(^{20}\)The six estimates that are not significant are those corresponding to portfolios 1, 3, 4, 8, 13, and 18. All of them are negative except for the coefficient on portfolio 4, which is positive and small.
to a 1 pp increase in the policy rate. The magnitudes of the H-based estimates tend to be larger than the E-based estimates. The sign and ranking of the H-based estimates across portfolios are roughly in line with the predictions of the theory. All the coefficients in the column labeled “Return” are negative and the magnitude of the (statistically significant) estimates tends to increase with the turnover liquidity of the portfolio.\footnote{With the exception of those corresponding to portfolios 3 and 4, all the H-based estimates of the responses of returns reported in Table 2 are statistically significant at the 5% level.} For example, a 1 pp increase in the policy rate causes a decrease of 3.4 pps in the return of portfolio 1 and a decrease of 12 pps in the return of portfolio 20. Fifteen of the coefficients in the column labeled “Turnover” are negative and statistically significant (at the 5% level), as predicted by the theory.\footnote{The five estimates that are not significant are those corresponding to portfolios 1, 3, 4, 8, and 18. All of them are negative except for the coefficient on portfolio 4, which is positive and small.} Also as predicted by the theory, the magnitude of the (statistically significant) coefficients tends to increase with the turnover liquidity of the portfolio. For example, the response of the turnover rate of portfolio 20 is about twelve times larger than the response of the turnover rate of portfolio 2.

As an alternative way to estimate the heterogeneous responses of returns to monetary policy shocks for stocks with different turnover liquidity, we ran an event-study regression of individual stock returns (for the universe of stocks listed in the NYSE) on changes in the policy rate, an interaction term between the change in the policy rate and individual stock turnover rate, and several controls. As before, \( \Delta i_t \) denotes the monetary policy shock on policy announcement day \( t \) (measured by the change between day \( t \) and day \( t-1 \) in the 3-month Eurodollar futures contract with nearest expiration after the day-\( t \) FOMC policy announcement) and \( T_t^s \) is the average turnover rate of the individual stock \( s \) over all the trading days during the four weeks prior to the day of the policy announcement of day \( t \). Let \( \Delta i_t \) and \( T_t \) denote the sample averages of \( \Delta i_t \) and \( T_t^s \), respectively, and define \( \overline{T_t^s} \equiv (T_t^s - T) \) and \( \overline{\Delta i_t} \equiv (\Delta i_t - \Delta i) \). The regression we fit is

\[
R_t^s = \beta_0 + \beta_1 \Delta i_t + \beta_2 T_t^s + \beta_3 \overline{T_t^s} \times \overline{\Delta i_t} + D_s + D_t + \beta_4 (\Delta i_t)^2 + \beta_5 (T_t^s)^2 + \varepsilon_{st},
\]

where \( D_s \) is a stock fixed effect, \( D_t \) is a quarterly time dummy, and \( \varepsilon_{st} \) is the error term corresponding to stock \( s \) on policy announcement day \( t \). The time dummies control for omitted variables that may affect the return of all stocks in the NYSE over time. The stock fixed effects control for the effects that permanent stock characteristics not included explicitly in the
regression may have on individual stock returns. We include the interaction term $T^2_t \times \Delta i_t$ to estimate how the effect of changes in the policy rate on individual stock returns vary across stocks with different turnover liquidity. The coefficient of interest is $\beta_3$, i.e., we want to test whether changes in the policy rate affect individual stock returns through the stock-specific turnover-liquidity channel. The estimate of $\beta_3$ can help us evaluate the theoretical prediction that increases (reductions) in the policy rate cause larger reductions (increases) in returns of stocks with larger turnover rate, i.e., the theory predicts $\beta_3 < 0$.

Table 3 reports the results from estimating five different specifications based on (24). Specification (I) excludes $D_s$, $D_t$, and the interaction term, $T^2_t \times \Delta i_t$. Specification (II) adds the interaction term to specification (I). Specification (III) adds $D_s$ to specification (II). Specification (IV) adds $D_t$ to specification (II). Specification (V) adds $D_s$ to specification (IV). Specification (VI), (VII), (VIII), and (IX) each adds the squared terms $(\Delta i_t)^2$ and $(T^2_t)^2$ to specification (II), (III), (IV), and (V), respectively. In all specifications, all estimates are significant at 1% level.

The estimate of $\beta_1$ is about $-2.4$ in specifications (I)-(V), implying that a 1 pp increase in the policy rate reduces the return of a stock with average turnover by 2.4 pps on the day of the policy announcement. Combined, the estimates of $\beta_1$ and $\beta_4$ in specifications (VI)-(IX) imply a stronger response of stock returns to the policy rate. For example, according to specification (IX) a 1 pp increase in the policy rate reduces the return of a stock with average turnover by 5.6 pps on the day of the policy announcement. The sign and magnitude of the latter estimates lie within the range of responses reported in Table 1.

The estimate of interest, $\beta_3$, is large and negative in all specifications, ranging from $-415$ (specification (VII)) to $-100$ (specification (IV)). The negative and statistical significant estimates of $\beta_3$ indicate that the magnitude of the negative effect of changes in the policy rate on announcement-day equity returns is larger for stocks with higher turnover liquidity. To interpret the magnitude of the estimates, consider an equity $A$ with turnover rate equal to 94.679 bps (i.e., an equity in the 95th percentile of turnover rates of the sample) and an equity $B$ with turnover rate equal to 5.975 bps (i.e., in the 5th percentile of turnover rates). Then, for example according to specification (IX), the estimate of $\beta_3$ is $-410$, implying that a 1 pp increase in the policy rate reduces the announcement-day return by $\beta_1 + 2\beta_4 + \beta_3 (T^2_t - T) \approx -4$ pps for equity $A$ and by $\beta_1 + 2\beta_4 + \beta_3 (T^2_t - T) \approx -3.4$ pps for equity $B$. Together with the findings reported in Table 1 and Table 2, these results provide additional evidence that turnover liquidity is a

---

23Average daily turnover in our sample is .0035.
6.4 Dynamic effects

In the previous section we have documented the “instantaneous” effect of monetary policy shocks on equity returns and turnover, i.e., the effect on the day the policy announcement takes place. While the turnover liquidity channel highlighted by our theory predicts the effects on announcement days documented in the previous section, the theoretical channel is eminently dynamic. In the theory, persistent changes in the nominal rate affect stock returns because they imply persistent changes future stock turnover. To study the dynamic effects of monetary policy on prices and turnover rates, we conduct a vector autoregression (VAR) analysis.

The baseline VAR we estimate consists of three variables, i.e., \( \{ i_t, R_I^t, T_I^t \}_{t \in S_0 \cup S_1} \), where \( i_t \), \( R_I^t \), and \( T_I^t \) are the daily measures of the policy rate, the stock return, and turnover described in Sections 6.1 and 6.2.\(^{24}\) The lag length is set to 10.\(^{25}\) To identify the effects of monetary policy shocks we apply an identification scheme based on an external high-frequency instrument.\(^{26}\)

Figure 2 reports the impulse responses of the policy rate, the average stock return, and the average turnover rate, to a 1 pp increase in the policy rate. The 95% confidence intervals are computed using a recursive wild bootstrap based on 10,000 replications.\(^{27}\) The top and bottom rows show responses for forecast horizons of 30 days and 120 days, respectively. The path of the policy rate is quite persistent; it remains significantly above the level prevailing prior to the shock for about one year. The middle panels of Figure 2 show the response of daily stock returns. On impact, in response to the 1 pp unexpected increase in the nominal rate, the stock

---

\(^{24}\)In Section 6.2 we used the change in the 3-Month Eurodollar futures rate on the day of the FOMC announcement as a proxy for the unexpected component of the change in the true policy rate, i.e., the effective fed funds rate. In this section we instead regard the 3-Month Eurodollar futures rate as the policy rate itself. We do this because, at a daily frequency, the effective fed funds rate is very volatile for much of our sample, e.g., due to institutional considerations, such as “settlement Wednesdays.” The path of the 3-Month Eurodollar futures rate is quite similar to the effective fed funds rate but it does not display the large regulation-induced weekly swings. In any case, we have also performed the estimation in this section using the daily effective fed funds rate instead of the Eurodollar futures rate, and the results for returns and turnover are quite similar.

\(^{25}\)The Akaike information criterion (AIC) suggests 10 lags, while Schwarz’s Bayesian information criterion (SBIC) and the Hannan and Quinn information criterion (HQIC) suggest 5 lags. We adopted the formulation with 10 lags but both formulations deliver similar estimates of the theoretical impulse responses implied by our quantitative theory (see Appendix B.1.3 for details).

\(^{26}\)See Appendix B.1.1 for details. The basic idea of SVAR identification using instruments external to the VAR can be traced back to Romer and Romer (1989) and has been adopted in a number of more recent papers, including Cochrane and Piazzesi (2002), Hamilton (2003), Kilian (2008a,b), Stock and Watson (2012), Mertens and Ravn (2013), and Gertler and Karadi (2015).

\(^{27}\)The procedure to calculate the confidence intervals is described in Appendix B.1.2. See Gonçalves and Kilian (2004) for a formal econometric analysis of this method.
return falls by about 7 pps (the 95% confidence band ranges from −8.03 to −6.24 pps). Notice that the size and magnitude of this decrease in stock return on the day of the policy shock in line with the estimates reported in Table 1. The negative effect on the stock return is relatively short lived: it becomes statistically insignificant about two days after the policy shock, and according to the point estimates, it takes about 1 day to recover half of the initial drop. The last column of Figure 2 shows the response of the level of the daily turnover rate. On impact, a 1 pp surprise increase in the nominal rate causes a change in the level of the turnover rate equal to −0.0038 (the 95% confidence band ranges from −0.0047 to −0.0035), which is similar to the H-based point estimate reported in Table 1. According to the point estimates, it takes about 1 day for the turnover rate to recover half of the initial drop. However, beyond that point the negative effect of the increase in the policy rate is quite persistent (e.g., it takes about 50 days for it to become statistically insignificant).

Bernanke and Kuttner (2005) is one of the few papers that tries to identify the economic forces behind the negative effect of nominal rate increases on stock returns. They use a VAR to decompose excess equity returns into components attributable to news about dividends, real interest rates, and future excess returns. They find that the component associated with future excess returns accounts for the largest part of the response of stock prices to changes in the nominal rate. This means that an increase in the policy rate lowers stock prices mostly by increasing the expected equity premium. Bernanke and Kuttner speculate that this could come about via some unspecified mechanism through which tight money increases the riskiness of stocks or decreases the investor’s willingness to bear risk. In this section we have provided empirical evidence for the novel mechanism suggested by our theory, i.e., that (at least part of) this increase in future excess returns comes about because tight money reduces the turnover liquidity of stocks (as measured by the stock turnover rate). Specifically, a higher nominal rate makes the payment instruments (e.g. bank reserves, real money balances) more scarce, which reduces the resalability and turnover, and this increased illiquidity is reflected in a reduction of the equity price.

7 Quantitative analysis

The theoretical result we used to motivate these regressions of Section 6 (i.e., part (i) of Proposition 3 and part (i) of Proposition 6) is akin to an experiment consisting of a permanent and entirely unanticipated increase in the nominal rate, so while suggestive, it is not a theoretical
experiment that corresponds strictly to the empirical estimates we reported in Section 6. In order to properly assess the predictions and quantitative performance of the theory, in this section we formulate, calibrate, and simulate a generalized version of the model of Section 2. Specifically, we simultaneously extend the model in two directions. First, we incorporate aggregate uncertainty regarding the path of monetary policy (implemented through changes in the nominal interest rate). This extension allows us to consider theoretical experiments that resemble more closely what goes on in financial markets, in the sense that while investors may be surprised by the timing and size of changes in the nominal rate, they take into account a probability distribution over future paths of the monetary policy so these changes are not entirely unexpected. Second, we extend the model to the case of multiple assets that differ in their liquidity properties. This extension allows us to provide additional evidence for the turnover liquidity mechanism by exploiting the cross-sectional heterogeneity and using it to assess the quantitative theoretical effects of monetary policy on the cross section of asset returns and turnover.

7.1 Generalized model

There are $N$ asset classes (or types), each indexed by $s \in \mathbb{N} = \{1, 2, ..., N\}$. The outstanding quantity of equity shares of type $s$ is $A^s$. Since the focus is on the implication of liquidity differences across asset classes, we assume each asset gives the same dividend $y_t$, which follows the same stochastic process described in the one-asset model of Section 2. An investor’s period-valuation of the dividend of any asset is distributed independently over time and across investors, with cumulative distribution function $G$, just as in the one-asset setup.

We model liquidity differences as follows. In each round of OTC trade, each investor can trade asset type $s \in \mathbb{N}$ with probability $\alpha^s \in [0, 1]$. The event that the investor is able to trade asset type $s$ is independent of the event that he is able to trade any other asset type $n \in \mathbb{N}$. We interpret $\alpha^s$ as the probability that an individual investor contacts a dealer with whom he can trade asset type $s$. This captures the idea that dealers are somehow specialized in trading a particular asset class.\footnote{In a large class of models that includes this one, Duffie et al (2005), and Lagos and Rocheteau (2009), the equilibrium asset price depends on the product of investors’ trading probability and their bargaining power in negotiations with dealers. So although here we model assets as differing only in the trading probability, conceptually for asset pricing purposes, we could interpret these differences as capturing differences in trading probabilities and bargaining power.} In each OTC trading round there are $N$ competitive interdealer markets, one for each asset class. These markets are segmented in the following sense: (i) asset
s can only be traded in market s, and (ii) in the second subperiod of every period t, investors choose equity holdings and partition their money holdings into N portfolios, i.e., each agent chooses \( \{a_{i+1}^{s}, a_{i+1}^{ms}\}_{s \in \mathbb{N}} \), where \( a_{i+1}^{s} \) denotes the holding of asset s, and \( a_{i+1}^{ms} \) is the amount of money the investor will have available to trade in the OTC market for asset class s of period \( t+1 \). For simplicity, in this section we assume dealers do not hold asset inventories overnight (and without loss of generality, also that they do not hold money overnight).

In Section 2 we assumed a constant growth rate of the money supply, i.e., \( A_{t+1}^{m} = \mu A_{t}^{m} \), where \( \mu \in \mathbb{R}_{++} \). Here we instead assume \( A_{t+1}^{m} = \mu_{t} A_{t}^{m} \) where \( \{\mu_{t}\}_{t=1}^{\infty} \), follows a Markov chain with \( \sigma_{ij} = \Pr (\mu_{t+1} = j | \mu_{t} = i) \) and \( \mu_{t} \in \mathbb{R}_{++} \) for all \( i, j \in \mathbb{M} = \{0, 1, \ldots, M\} \). The realization of \( \mu_{t} \) is known at the beginning of period t. As before, money is injected via lump-sum transfers to investors in the second subperiod of every period.

We specialize the analysis to recursive equilibria in which prices are time-invariant functions of the aggregate state, \( x_{t} = (A_{t}^{m}, y_{t}, \mu_{t}) \in \mathbb{R}_{++}^{2} \). That is, \( \phi_{t}^{s} = \phi^{s}(x_{t}), \tilde{\phi}_{t}^{s} = \tilde{\phi}^{s}(x_{t}), \tilde{\phi}_{t}^{m} = \phi^{m}(x_{t}), p_{t}^{s} = p^{s}(x_{t}), \) and \( \varepsilon_{t}^{**} = \varepsilon^{**}(x_{t}) \). We conjecture the recursive equilibrium has the property that real prices are linear functions of the aggregate dividend, i.e., suppose \( x_{t} = (A_{t}^{m}, y_{t}, \mu_{t}) \), then \( \phi^{s}(x_{t}) = \tilde{\phi}_{t}^{s} y_{t}, \tilde{\phi}^{s}(x_{t}) = \phi_{t}^{s} y_{t}, \phi^{m}(x_{t}) = A_{t}^{m}, \varepsilon^{**}(x_{t}) = [\tilde{\phi}^{s}(x_{t}) - \phi^{s}(x_{t})] / y_{t} = \phi_{t}^{s} - \tilde{\phi}_{t}^{s} = \varepsilon_{t}^{**} \), and \( \phi^{m}(x_{t}) A_{t}^{ms} = Z_{t}^{y}, \) where \( A_{t}^{ms} \) denotes the amount of money that investors have chosen to have available to trade asset type s in the OTC round of period t. In Appendix B we show that an equilibrium is characterized by a vector \( \{\varepsilon_{t}^{**}, \phi_{t}^{s}, Z_{t}^{s}, Z_{t}^{y}\}_{t \in \mathbb{M}, s \in \mathbb{N}} \) of \( M (3N + 1) \) unknowns that solves the following system of \( M (3N + 1) \) equations

\[
\phi_{t}^{s} = \bar{\theta} \sum_{j \in \mathbb{M}} \sigma_{ij} \left[ \varepsilon + \phi_{t}^{s} + \alpha^{s} \theta \int_{\varepsilon_{j}^{**}}^{\varepsilon_{j}^{**}} (\varepsilon^{**} - \varepsilon) dG(\varepsilon) \right] \text{ for all } (i, s) \in \mathbb{M} \times \mathbb{N} \tag{25}
\]

\[
Z_{t} = \frac{1}{\mu_{t}} \sum_{j \in \mathbb{M}} \sigma_{ij} \left[ Z_{j} + \alpha^{s} \theta \int_{\varepsilon_{j}^{**}}^{\varepsilon_{j}^{**}} (\varepsilon - \varepsilon^{**}) dG(\varepsilon) \frac{Z_{j}}{\varepsilon_{j}^{**} + \theta} \right] \text{ for all } (i, s) \in \mathbb{M} \times \mathbb{N} \tag{26}
\]

\[
Z_{t}^{s} = \frac{G(\varepsilon_{t}^{**}) A_{t}^{s}}{1 - G(\varepsilon_{t}^{**})} (\varepsilon_{t}^{**} + \phi_{t}^{s}) \text{ for all } (i, s) \in \mathbb{M} \times \mathbb{N} \tag{27}
\]

\[
Z_{t}^{y} = \sum_{s \in \mathbb{N}} Z_{t}^{s} \text{ for all } i \in \mathbb{M}. \tag{28}
\]

In the following subsections we calibrate and simulate this generalized model to assess the ability of the theory to account for the empirical findings reported in Section 6. Before doing so, it is useful to define the theoretical analogues to the variables we studied in the empirical
The return of stock $s$ at date $t+1$ is $R_{t+1}^s = \frac{\bar{\phi}_{t+1}^s}{\phi_{t}^s} - 1$, where $\bar{\phi}_{t+1}^s \equiv p_t \phi_{t+1}^m = \phi_{t+1}^s + \varepsilon_t^s y_t$ is the cum dividend price of equity at date $t$ defined in Section 4. In a recursive equilibrium, suppose the state at date $t$ is $x_t = (A_t^m, y_t, \mu_i)$ and at date $t+1$ is $x_{t+1} = (\mu_i A_t^m, y_{t+1}, \mu_j)$, then

$$R_{t+1}^s = \frac{\phi_{t+1}^s + \varepsilon_{t+1}^s}{\phi_t^s} y_{t+1} - 1.$$

So far we have implicitly assumed that $A^s$, i.e., all outstanding equity shares of type $s$, are actively traded every day. In actual markets, however, a fraction of the outstanding equity shares are seldom traded (stocks held in 401(k) accounts, for example). Our theory remains unchanged if we replace $A^s$ with $\kappa A^s$ for some $\kappa \in [0,1]$ that represents the proportion of the universe of outstanding stocks that are actively traded and think of the remaining $(1-\kappa)A^s$ as being held by non-traders outside the model. In an equilibrium in which dealers do not hold assets (as is the case in this section), trade volume for asset type $s$ at date $t$ is $V_t^s = 2\alpha_s G(\varepsilon_t^s) \kappa A^s$. A conventional measure of trade volume is the turnover rate used in the empirical work of Section 6.1. According to the theory, the turnover rate on date $t$ is

$$T_t^s = V_t^s / A^s = 2\alpha_s G(\varepsilon_t^s) \kappa.$$

Naturally, a nonzero fraction of inactive stocks (i.e., $\kappa < 1$) lowers the measured turnover rate. In a recursive equilibrium, suppose the state at date $t$ is $x_t = (A_t^m, y_t, \mu_i)$, then the turnover rate can be written as $T_t^s = 2\alpha_s G(\varepsilon_t^s) \kappa$.

In the theory as in our empirical work, whenever we use an average, e.g., of equity returns or turnover rates across a set of stocks, we use the arithmetic average, e.g., $R_t^s = \frac{1}{N} \sum_{s \in N} R_{t}^s$ and $T_t^s = \frac{1}{N} \sum_{s \in N} T_{t}^s$ are the average return and the average turnover rate for the universe of stocks in the theory.

Let $\psi^b(x_t)$ denote the state-$x_t$ real price of an illiquid one-period pure-discount nominal bond in the second subperiod of any period (the bond is illiquid in the sense that cannot be traded in the OTC market). The Euler equation for this asset is $\psi^b(x_t) = \beta E[\phi_{t+1}^m(x_t) | x_t]$. The dollar price of the asset in the second subperiod of period $t$ is $q(x_t) \equiv \psi^b(x_t) / \phi_{t}^m(x_t)$, so the Euler equation can be written as $q(x_t) = \beta / \bar{\pi}(x_t)$, where $\bar{\pi}(x_t) \equiv \frac{\phi_{t+1}^m(x_t)}{E[\phi_{t+1}^m(x_{t+1}) | x_t]}$. Then the

\[\text{Table 2 reports the annual turnover rates corresponding to each of the twenty portfolios we studied in Section 6.3. Notice that the turnover rates appear to be quite low: even the top 5% most traded stocks are only traded about 3 times per year, on average, which suggests the model should allow for the possibility of } \kappa < 1.\]
(net) nominal rate on this bond (between period $t$ and period $t+1$) is $r(\mathbf{x}_t) \equiv q(\mathbf{x}_t)^{-1} - 1 = \pi(\mathbf{x}_t)/\beta - 1$. Suppose $\mathbf{x}_t = (A_i^n, y_t, \mu_i)$, then in a recursive equilibrium, $\pi(\mathbf{x}_t) \equiv \pi_i$ and $r(\mathbf{x}_t) \equiv r_i = \pi_i/\beta - 1$, where $\pi_i = \mu_i / \sum_{j \in \mathcal{M}} \sigma_{ij} Z_j$. So the one-period risk-free nominal interest rate between time $t$ in state $\mathbf{x}_t = (A_i^n, y_t, \mu_i)$ and time $t+1$ is

$$r_i = \frac{\mu_i}{\beta} \sum_{j \in \mathcal{M}} \sigma_{ij} Z_j - 1. \quad(29)$$

### 7.2 Calibration

We think of one model period as being one day. The discount factor, $\beta$, is chosen so that the annual real risk-free rate equals 3 percent, i.e., $\beta = (0.97)^{1/365}$. Idiosyncratic valuation shocks are distributed uniformly on $[0, 1]$, i.e., $G(\varepsilon) = \mathbb{I}_{\{\varepsilon_L \leq \varepsilon \leq \varepsilon_H\}} \varepsilon + \mathbb{I}_{\{\varepsilon_H < \varepsilon\}}$ with $\varepsilon_L = 0$ and $\varepsilon_H = 1$. The dividend growth rate is independently lognormally distributed over time, with mean .04 and standard deviation .12 per annum (e.g., as documented in Lettau and Ludvigson (2005), Table 1). That is, $y_{t+1} = e^x_{t+1} y_t$, with $x_{t+1} \sim \mathcal{N}(\bar{\gamma} - 1, \Sigma^2)$, where $\bar{\gamma} - 1 = \mathbb{E}(\log y_{t+1} - \log y_t) = .04/365$ and $\Sigma = SD(\log y_{t+1} - \log y_t) = .12/\sqrt{365}$. The parameter $\delta$ can be taken as a proxy of the riskiness of stocks; a relatively low value ensures the monetary equilibrium exists even at relatively high inflation rates. We choose $\delta = (.7)^{1/365}$, i.e., a productive unit has a 70 percent probability of remaining productive each year. The number of outstanding shares of stocks of every class is normalized to 1, i.e., $A^s = 1$ for all $s \in \mathbb{N}$. We set $N = 20$ so the number of asset classes in the theory matches the number of synthetic empirical liquidity portfolios we considered in the cross-sectional analysis of Section 6.3. For each asset class $s \in \{1, \ldots, 19\}$ in the model, $\alpha^s$ is calibrated so that the long-run time-average of the equilibrium turnover rate, i.e., $\bar{T}_t^s \equiv \lim_{T \to \infty} \frac{1}{T} \sum_{t=1}^{T} T_t^s$, matches the turnover rate of the $s^{th}$ synthetic empirical liquidity portfolio in our sample. We normalize $\alpha^{20} = 1$ and calibrate the fraction of actively traded stocks, $\kappa$, so that the average turnover across all stocks in the model equals the average turnover across all stocks in our sample, i.e., so that $\frac{1}{20} \sum_{s=1}^{20} \bar{T}_t^s = .0035.30$

We set $\theta = 1$ in our baseline and abstract from micro-level pricing frictions induced by bargaining. Finally, we estimate the parameters that determine the monetary policy process, i.e., $\{\mu_i, \sigma_{ij}\}_{i,j \in \mathcal{M}}$ and $M$, as follows. We estimate the stochastic process for the policy rate using the futures rate of the 3-month Eurodollar deposit contract. The sample runs from January

---

30This procedure delivers $\alpha^1 = .0952$, $\alpha^2 = .1171$, $\alpha^3 = .1344$, $\alpha^4 = .1506$, $\alpha^5 = .1665$, $\alpha^6 = .1822$, $\alpha^7 = .1977$, $\alpha^8 = .2135$, $\alpha^9 = .2296$, $\alpha^{10} = .2467$, $\alpha^{11} = .2654$, $\alpha^{12} = .2849$, $\alpha^{13} = .3076$, $\alpha^{14} = .3341$, $\alpha^{15} = .3658$, $\alpha^{16} = .4051$, $\alpha^{17} = .4561$, $\alpha^{18} = .5287$, $\alpha^{19} = .6529$, and $\kappa = .03$. 

34
3, 1994 to November 26, 2001. We formulate that the logarithm of the policy rate follows an AR(1) process, we estimate this process at a daily frequency, and approximate it with a 7-state Markov chain, \( \{r_i, \sigma_{ij}\}_{i,j=1}^{7} \). From (29), there is a one-to-one mapping between the nominal rate and the money growth rate in the theory, and since the policy rate is estimated to be very persistent, we have \( r_i \approx \mu_i / \bar{\beta} - 1 \). Thus the money supply process we use to simulate the model is \( \{\mu_i, \sigma_{ij}\}_{i,j=1}^{7} \), where \( \sigma_{ij} \) are the estimated transition probabilities for the policy rate, and \( \mu_i \approx \bar{\beta}(1 + r_i) \).

In the remainder of the section we assess the ability of the theory to match the evidence documented in Section 6. To do so, we simulate the calibrated model as follows. First, for the calibrated model, compute the equilibrium functions characterized by (25)-(28). Simulate 1,000 samples of the dividend, each of length equal to our data sample. Set the path of the nominal rate in the model equal to the actual empirical path of the policy rate. Then compute the equilibrium of the model 1,000 times (one for each realization of the simulated dividend path) and for each simulated equilibrium path, compute the average daily equity return and turnover rate for each asset class.

### 7.3 Exercise 1: Aggregate announcement-day effects

The first exercise we conduct is the model analogue of the event-study regression analysis of Section 6.2. For each simulated equilibrium path for average daily stock return and turnover rate (i.e., the arithmetic average across the 20 stock classes), we run the event-study regression for returns (i.e., (21)) as well as for turnover (i.e., (21) but using the average level of turnover rate as dependent variable).

Figure 3 displays the distribution of point estimates for the response of daily return to the policy rate implied by these 1,000 regressions on simulated data. The average point estimate is \(-2.23\) (with standard deviation 1.08), which is quite close to the empirical (E-based) estimate of \(-3.77\) obtained in Section 6.2. In fact, Figure 3 shows that \(-3.77\) is within the 95\% confidence interval of the point estimates generated by the theory. Regarding the model response of the turnover rate, the average point estimate is \(-.0001\), two orders of magnitude smaller than the empirical point (E-based) estimate of \(-.0025\) obtained in Section 6.2. These comparisons are

Specifically, the process we estimate is \( \ln i_t = (1 - \xi)\ln i_{t-1} + \xi \ln i_{t-1} + \varepsilon_t \), where \( \varepsilon_t \) is Gaussian white noise. With \( i_t \) denominated in basis points, the estimate of \( \xi \) is 0.9997652, the estimate of \( \ln i_0 \) is 5.7362, and the estimate of the standard deviation of \( \varepsilon_t \) is 0.0102. The estimated AR(1) process is very persistent so, as suggested by Galindev and Lkhagvasuren (2010), we use the Rouwenhorst method to compute the approximating Markov matrix and states. The code for the Rouwenhorst method is also from Galindev and Lkhagvasuren (2010).
limited to the announcement-day responses. As we show below, although the model response for turnover is small on impact, it is very persistent and tends to converge to the empirical response in subsequent days.

7.4 Exercise 2: Disaggregative announcement-day effects

The second exercise is the model analogue of the cross-sectional event-study analysis of Section 6.2. For each of the twenty asset classes, we run an event-study regression for returns and an event-study regression of turnover using the simulated equilibrium path for daily stock return and turnover rate for that particular asset class.

The results for returns are illustrated in Figure 4, which reports the estimates from the model simulation along with the empirical E-based estimates from Table 2 and the corresponding 95% confidence intervals. The magnitudes of the model estimates is somewhat smaller than the empirical counterparts, but they all fall within the 95% confidence bands of the empirical estimates. Also, the slope of the response appears to be somewhat steeper in the data.

The results for turnover are illustrated in Figure 5, which reports which reports the estimates from the model simulation along with the empirical E-based estimates from Table 2 and the corresponding 95% confidence intervals. The estimates in the figure have been normalized by the average of the estimates across portfolios. That is, the response of each portfolio is expressed as a multiple of the average response. This allows us to focus on the magnitude of the relative response of turnover across asset classes. For example, both in the empirical and in the model regression, the magnitude of the drop in turnover of portfolio 13 is similar to that of the average portfolio. The magnitude of the response for portfolios with turnover lower (higher) than portfolio 13 is lower (higher) than the average. The relative magnitudes of the model responses are to a large extent in line with those estimated from the data (the model only misses the particularly large relative responses of portfolios 17 through 20).

7.5 Exercise 3: VAR analysis

The third exercise is the model analogue to the VAR analysis of Section 6.4. For each simulated equilibrium path for average daily return and turnover rate, we estimate the impulse responses to a 1 pp increase in the policy rate using exactly the same procedure used to estimate the

\[\text{32}\text{The confidence intervals for the empirical estimates are from the OLS estimations, while the confidence intervals for the theoretical estimates are based on the distribution of estimates from the 1,000 simulations.}\]
impulse responses from the data, as described in Section 6.4 and Appendix B.1.\textsuperscript{33}

Figure 6 reports the model impulse responses of the policy rate, the average stock return, and the average turnover rate, to a 1 pp increase in the policy rate, along with the corresponding empirical impulse responses estimated from actual data. The top and bottom rows show responses for forecast horizons of 30 days and 120 days, respectively.

The path of the policy rate from the model is quite close to the empirical path (e.g., the estimated dynamic response falls within the 95% confidence intervals of the empirical impulse response for the first 80 days). The middle panels show the response of daily stock returns. On impact, in response to the 1 pp unexpected increase in the nominal rate, the model stock return falls by $-4.36$ pps, which is a little over sixty percent of the size of the empirical estimate. The theoretical impulse response is quite close to the empirical estimates in the sense that if falls within the 95% confidence interval estimated from the data. In particular, just as in the data, the negative effect of the policy rate increase on the stock return is relatively short lived: it becomes statistically insignificant about 2 days after the policy shock, and it takes about 1 day to recover half of the initial drop. The last column of Figure 6 shows the response of the level of the daily turnover rate. On impact, in response to the 1 pp unexpected increase in the nominal rate, the turnover rate falls by $-0.0001$ in the model, which, consistent with the findings in Section 7.3, is much smaller than than the empirical estimate ($-0.0038$ on impact according to the estimated impulse response). However, although the model response for turnover is smaller on impact, it is very persistent and tends to converge to the empirical response in subsequent days. For example, the difference between the empirical path for turnover rate and the theoretical path becomes statistically insignificant after about 30 days. This persistent effect of policy on the turnover rate is what explains why the model can generate a short-run response in return that is quantitatively in line with the data although the announcement-day effect on turnover appears to be much smaller than in the data.\textsuperscript{34}

\textsuperscript{33}For the purposes of the VAR exercises, we add a small noise term (drawn i.i.d. from a uniform distribution on $[-5 \times 10^{-7}, 5 \times 10^{-7}]$) to the simulated turnover rate. We do this to ensure that return and turnover are not perfectly collinear in the simulated equilibrium. Adding noise to the turnover rate does not alter the equilibrium conditions in any way.

\textsuperscript{34}Figure 7, discussed in Appendix B.1.3, shows that according to the model, the VAR procedure may be overestimating the announcement-day effect of the policy rate on turnover and underestimating the persistence of the effect.
8 Related literature

The empirical component of our paper (Section 6) is related to a large empirical literature that studies the effect of monetary policy shocks on asset prices. Like many of these studies, we identify monetary policy shocks by focusing on the reaction of asset prices in a narrow time window around FOMC monetary policy announcements. Cook and Hahn (1989), for example, use this kind of event-study identification strategy (with an event window of one day) to estimate the effects of changes in the federal funds rate on bond rates. Kuttner (2001) conducts a similar analysis but shows the importance of focusing on unexpected policy changes, that he proxies for with federal funds futures data. Cochrane and Piazzesi (2002) estimate the effect of monetary policy announcements on the yield curve using a one-day window around the FOMC announcement and the daily change in the one-month Eurodollar rate to proxy for unexpected changes in the fed funds rate target. Bernanke and Kuttner (2005) use daily event windows around FOMC announcements to estimate the effect of unexpected changes in the fed funds rate (measured using fed funds futures data) on the return of broad stock indices. Gürkaynak, Sack and Swanson (2005) focus on intraday event windows around FOMC announcements (30 minutes or 60 minutes wide) to estimate the effects on the S&P500 return and several Treasury yields of unexpected changes in the fed funds target and “forward guidance” (i.e., information on the future path of policy contained in the announcement). More recently, Hanson and Stein (2015) estimate the effect of monetary policy shocks on the nominal and real Treasury yield curves using a two-day window around the announcement. Nakamura and Steinsson (2015) also estimate the effects of monetary policy shocks on the nominal and real Treasury yield curves but they use a thirty-minute window around the announcement. Gertler and Karadi (2015) also use a thirty-minute window around the announcement to estimate the response of bond yields and credit spreads to monetary policy shocks. Rigobon and Sack (2004) propose a heteroskedasticity-based estimator to correct for possible simultaneity biases remaining in these event-study regressions.

Relatively fewer papers have attempted to identify the precise mechanism through which surprise increases in the fed funds rate lead to a reduction stock prices. Bernanke and Kuttner (2005), for example, take one step in this direction by analyzing the response of more disaggregated indices, in particular 10 industry-based portfolios. They find that the precision of their estimates is not sufficient to reject the hypothesis of an equal reaction for all 10 industries.
Firms differ along many dimensions, however, and a number of studies have focused on how these may be related to different responses of their stock prices to policy shocks. Ehrmann and Fratzscher (2004), for example, find that firms with low cash flows, small firms, firms with low credit ratings, firms with high price-earnings multiples, or firms with high Tobin’s q, exhibit a higher sensitivity to monetary policy shocks. Ippolito et al. (2013) find that the stock prices of bank-dependent firms that borrow from financially weaker banks display a stronger sensitivity to monetary policy shocks while bank-dependent firms that hedge against interest rate risk display a lower sensitivity to monetary policy shocks. Gorodnichenko and Weber (2016) document that after monetary policy announcements, the conditional volatility of stock market returns rises more for firms with stickier prices than for firms with more flexible prices. Relative to this literature, our contribution is to document and offer a theory the \textit{turnover liquidity transmission mechanism} that channels monetary policy to asset prices.

From a theoretical standpoint, the model we develop in this paper bridges the search-theoretic monetary literature that has largely focused on macro issues, and the search-theoretic financial OTC literature that focuses on micro considerations in the market microstructure tradition. Specifically, we embed an OTC financial trading arrangement similar to Duffie et al. (2005) into a Lagos and Wright (2005) economy. Despite several common ingredients with those papers, our formulation is different from previous work along two important dimensions.

In the standard formulations of the Lagos-Wright framework, money (and sometimes other assets) are used as payment instruments to purchase consumption goods in bilateral markets mediated by search. We instead posit that money is used as a medium of exchange in OTC markets for financial assets. In the standard monetary model, money and other liquid assets help to allocate goods from producers to consumers, while in our current formulation, money helps to allocate financial assets among traders with heterogeneous valuations. This shift in the nature of the gains from trade offers a different perspective that delivers novel insights on the interaction between monetary policy and financial markets. For example, from a normative standpoint, the new angle emphasizes a new angle on the welfare cost of inflation that is associated to the distortion of the optimal allocation of financial assets across high and low valuation investors when real balances scarce. From a positive angle, it explains the positive correlation between nominal bond yields and real equity yields, something that the conventional formulation in which monetary or real assets are used to buy consumption goods cannot do.

As a model of financial trade, an appealing feature of Duffie et al. (2005) is its realistic OTC
market structure consisting of an interdealer market and bilateral negotiated trades between investors, and between investors and dealers. In Duffie et al. (2005), agents who wish to buy assets pay sellers with linear-utility transfers. In addition, utility transfers from buyers to sellers are unconstrained, so effectively there is no bound to what buyers can afford to purchase in financial transactions. Our formulation keeps the appealing market structure of Duffie et al. (2005) but improves upon its stylized model of financial transactions by considering traders who face standard budget constraints and use fiat money to purchase assets. These modifications make the standard OTC formulation amenable to general equilibrium analysis and deliver a natural transmission mechanism through which monetary policy influences asset prices and the standard measures of financial liquidity that are the main focus of the micro strand of the OTC literature.

Our theoretical work is related to several previous studies, e.g., Geromichalos et al. (2007), Jacquet and Tan (2010), Lagos and Rocheteau (2008), Lagos (2010a, 2010b, 2011), Lester et al. (2012), Nosal and Rocheteau (2013), that introduce a real asset that can (at least to some degree) be used along with money as a medium of exchange for consumption goods in variants of Lagos and Wright (2005). These papers identify the liquidity value of the asset with its usefulness in exchange, and find that when the asset is valuable as a medium of exchange, this manifests itself as a “liquidity premium” that makes the real asset price higher than the expected present discounted value of its financial dividend. High anticipated inflation reduces real money balances; this tightens bilateral trading constraints, which in turn increases the liquidity value and the real price of the asset. In contrast, we find that real asset prices are decreasing in the rate of anticipated inflation. There are some models that also build on Lagos and Wright (2005) where agents can use a real asset as collateral to borrow money that they subsequently use to purchase consumption goods. In those models, anticipated inflation reduces the demand for real balances which can in turn reduce the real price of the collateral asset needed to borrow money (see, e.g., He et al., 2012, and Li and Li, 2012). The difference is that in our setup inflation reduces the real asset price by constraining the reallocation of the financial asset from investors with low valuations to investors with relatively high valuations.35

We share with two recent papers, Geromichalos and Herrenbrueck (2012) and Trejos and

35In the model that we have developed here, money is the only asset used as means of payment. It would be straightforward, however, to enrich the asset structure so that investors may choose to carry other real assets that can be used as means of payment in the OTC market, e.g., along the lines of Lagos and Rocheteau (2008) or Lagos (2010a, 2010b, 2011). As long as money is valued in equilibrium, we anticipate that the main results emphasized here would continue to hold.
Wright (2012), the general interest in bringing models of OTC trade in financial markets within the realm of modern monetary general equilibrium theory. Trejos and Wright (2012) offer an in-depth analysis of a model that nests Duffie et al. (2005) and the prototypical “second generation” monetary search model with divisible goods, indivisible money and unit upper bound on individual money holdings (e.g., Shi, 1995 or Trejos and Wright, 1995). Trejos and Wright emphasize the different nature of the gains from trade in both classes of models. In monetary models agents value consumption goods differently and use assets to buy goods, while in Duffie et al. (2005) agents trade because they value assets differently, and goods which are valued the same by all investors are used to pay for asset purchases. In our formulation there are gains from trading assets, as in Duffie et al. (2005), but agents pay with money, as in standard monetary models. Another difference with Trejos and Wright (2012) is that rather than assuming indivisible assets and unit upper bound on individual asset holdings as in Shi (1995), Trejos and Wright (1995) and Duffie et al. (2005), we work with divisible assets and unrestricted portfolios, as in Lagos and Wright (2005) and Lagos and Rocheteau (2009).

Geromichalos and Herrenbrueck (2016) extend Lagos and Wright (2005) by incorporating a real asset that by assumption cannot be used to purchase goods in the decentralized market (as usual, at the end of every period agents choose next-period money and asset portfolios in a centralized market). The twist is that at the very beginning of every period, agents learn whether they will want to buy or sell consumption goods in the subsequent decentralized market and at that point they have access to a bilateral search market where they can retrade money and assets. This market allows agents to rebalance their positions depending on their need for money, e.g., those who will be buyers seek to buy money and sell assets. So although assets cannot be directly used to purchase consumption goods as in Geromichalos et al. (2007) or Lagos and Rocheteau (2008), agents can use assets to buy goods indirectly, i.e., by exchanging them for cash in the additional bilateral trading round at the beginning of the period. Geromichalos and Herrenbrueck use the model to revisit the link between asset prices and inflation. Mattesini and Nosal (2016) study a related model that combines elements of Geromichalos and Herrenbrueck (2016) and elements of Lagos and Zhang (2015) but considers a new market structure for the interdealer market.

The fact that the equilibrium asset price is larger than the expected present discounted value that any agent assigns to the dividend stream is reminiscent of the literature on speculative trading that can be traced back to Harrison and Kreps (1978). As in Harrison and Kreps...
and more recent work, e.g., Scheinkman and Xiong (2003a, 2003b) and Scheinkman (2013), speculation in our model arises because traders have heterogeneous asset valuations that change over time: investors are willing to pay for the asset more than the present discounted value that they assign to the dividend stream, in anticipation of the capital gain they expect to obtain when reselling the asset to higher-valuation investors in the future. In terms of differences, in the work of Harrison and Kreps or Scheinkman and Xiong, traders have heterogeneous stubborn beliefs about the stochastic dividend process, and their motive for trading is that they all believe (at least some of them mistakenly) that by trading the asset they can profit at the expense of others. In our formulation traders simply have stochastic heterogeneous valuations for the dividend, as in Duffie et al. (2005). Our model offers a new angle on the speculative premium embedded in the asset price, by showing how it depends on the underlying financial market structure and the prevailing monetary policy that jointly determine the likelihood and profitability of future resale opportunities. Through this mechanism our theory can generate a positive correlation between trade volume and the size of speculative premia, a key stylized fact that the theory of Scheinkman and Xiong (2003b) also explains.

Piazzesi and Schneider (2016) also emphasize the general idea that the cost of liquidity can affect asset prices. In their model the cost of liquidity to end users depends on the cost of leverage to intermediaries, while our model and our empirical work instead center around the role of the nominal policy rate, which represents the cost of holding the nominal assets used routinely to settle financial transactions (e.g. bank reserves, real money balances).

9 Conclusion

We conclude by mentioning what we think are three promising avenues for future work. First, in the model we have presented, all asset purchases are paid for with outside money. In other words, it focuses on the relevant margin for settings, transactions, or traders for which credit limits have become binding. While arguably stark, we think this formulation is a useful benchmark to contrast with the traditional asset pricing literature that abstracts from the role of costly or scarce payment instruments. Having said this, we think it would be interesting to extend the theory to allow for credit arrangements. The possibility of “buying on margin,” for example, could very well magnify some of the monetary mechanisms we have emphasized here. Second, given trading frictions in the exchange process are at the center of the analysis (e.g., the likelihood of finding a counterparty, or the market power of dealers who intermediate
transactions), it would be interesting to endogenize them (see Lagos and Zhang (2015) for some work in this direction). Third, while our empirical work has focused on stocks, the transmission mechanism we have identified is likely to be operative—and possibly even stronger and more conspicuous—in markets for other assets, such as Treasuries and assets that trade in more frictional over-the-counter markets.
A Proofs

Proof of Proposition 1. The choice variable $a'_{Dt}$ does not appear in the Planner’s objective function, so $a'_{Dt} = 0$ at an optimum. Also, (3) must bind for every $t$ at an optimum, so the planner’s problem is equivalent to

$$\max_{(\tilde{a}_{Dt}, \tilde{a}_{It})} \sum_{t=0}^{\infty} \beta^t \left[ \alpha \int_{\bar{\varepsilon}}^{\varepsilon_H} \varepsilon (d\varepsilon) + (1 - \alpha) \tilde{\varepsilon} a_{It} \right] y_t$$

s.t. (1), (4), (5), and $\alpha \int_{\bar{\varepsilon}}^{\varepsilon_H} \varepsilon (d\varepsilon) \leq a_{Dt} + \alpha a_{It}$.

Let $W^*$ denote the maximum value of this problem. Then clearly, $W^* \leq \bar{W}^*$, where

$$\bar{W}^* = \max_{\tilde{a}_{It}} \sum_{t=0}^{\infty} \beta^t \left[ \varepsilon (A^s - (1 - \bar{\varepsilon}) A^s) \tilde{\varepsilon} a_{It} \right] \delta y_t + w$$

s.t. (1), where $w = [\alpha \varepsilon_H + (1 - \alpha) \bar{\varepsilon}] (1 - \delta) A^s \sum_{t=0}^{\infty} \beta^t y_t$. Rearrange the expression for $\bar{W}^*$ and substitute (1) (at equality) to obtain

$$\bar{W}^* = \max_{\tilde{a}_{It}} \sum_{t=0}^{\infty} \beta^t \left\{ \varepsilon (A^s - (1 - \bar{\varepsilon}) \tilde{\varepsilon} a_{It}) \right\} \delta y_t + w$$

The allocation consisting of $\tilde{a}_{Dt} = A^s$, $\tilde{a}_{It} = 0$, and the Dirac measure defined in the statement of the proposition achieve $\bar{W}^*$ and therefore solve the Planner’s problem.

Proof of Lemma 1. Notice that (8) implies

$$W^D_t (a_t, k_t) = \phi_t a_t + k_t + W^D_t$$

where

$$W^D_t = \max_{\tilde{a}_{t+1} \in \mathbb{R}^2_+} \left[ -\phi_t \tilde{a}_{t+1} + \beta \mathcal{E}_t V^D_{t+1} (\tilde{a}_{t+1}, \delta \tilde{a}^s_{t+1}) \right],$$

so (7) implies

$$W^D_t (a_t, k_t) = k_t + W^D_t + \max_{\tilde{a}_{It}} \phi_t \tilde{a}_{It}$$

s.t. $\tilde{a}^m_t + p_t \tilde{a}^s_t \leq a^m_t + p_t a^s_t$. 

44
Hence

\[ \hat{a}_t^m (a_t) \begin{cases} = a_t^m + p_t a_t^s & \text{if } 0 < \varepsilon_t^* \\ \in [0, a_t^m + p_t a_t^s] & \text{if } \varepsilon_t^* = 0 \\ = 0 & \text{if } \varepsilon_t^* < 0, \end{cases} \]

\[ \hat{a}_t^s (a_t) = (1/p_t) [a_t^m + p_t a_t^s - \hat{a}_t^m (a_t)], \]

and

\[ \hat{W}_t^D (a_t, k_t) = \max (\phi_t^m, \phi_t^s/p_t) (a_t^m + p_t a_t^s) + k_t + \hat{W}_t^D. \] (31)

Also, notice that (9) implies

\[ W_t^I (a_t, -k_t) = \phi_t a_t - k_t + \hat{W}_t^I \] (32)

where

\[ \hat{W}_t^I \equiv T_t + \max_{a_{t+1} \in \mathbb{R}^2} \left[ -\phi_t \tilde{a}_{t+1} + \beta E_t \int V_{t+1}^I [\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s + (1 - \delta) A^s, \varepsilon] dG(\varepsilon) \right]. \] (33)

With (31) and (32), (6) can be written as

\[ \max_{a_t^m, k_t} \left[ (\varepsilon_t^* - \varepsilon) (\overline{a}_t^m - a_t^m) 1/p_t y_t - k_t \right]^\theta k_t^{1-\theta} \]

s.t. \( 0 \leq k_t \leq (\varepsilon_t^* - \varepsilon) (\overline{a}_t^m - a_t^m) 1/p_t y_t \)

with \( \overline{a}_t^m = a_t^m + (1/p_t) (a_t^m - \overline{a}_t^m). \) Hence

\[ \overline{a}_t^m (a_t, \varepsilon) \begin{cases} = a_t^m + p_t a_t^s & \text{if } \varepsilon < \varepsilon_t^* \\ \in [0, a_t^m + p_t a_t^s] & \text{if } \varepsilon = \varepsilon_t^* \\ = 0 & \text{if } \varepsilon_t^* < \varepsilon, \end{cases} \]

\[ \overline{a}_t^s (a_t, \varepsilon) = a_t^s + (1/p_t) [a_t^m - \overline{a}_t^m (a_t, \varepsilon)], \]

and

\[ k_t (a_t, \varepsilon) = (1 - \theta) (\varepsilon - \varepsilon_t^*) \left[ 1_{\{\varepsilon_t^* < \varepsilon\}} 1/p_t a_t^m - 1_{\{\varepsilon < \varepsilon_t^*\}} a_t^s \right] y_t. \]

This concludes the proof. \( \blacksquare \)

**Lemma 2** Let \( (\tilde{a}_{t+1}^m, \tilde{a}_{t+1}^s) \) and \( (\tilde{a}_{t+1}^m, \tilde{a}_{t+1}^s) \) denote the portfolios chosen by a dealer and an investor, respectively, in the second subperiod of period \( t \). These portfolios must satisfy the
following first-order necessary and sufficient conditions:

\[ \phi^m_t \geq \beta \mathbb{E}_t \max \{ \phi^m_{t+1}, \phi^s_{t+1}/p_{t+1} \}, \text{ with } "= " \text{ if } \tilde{a}^m_{dt+1} > 0 \]  
(34)

\[ \phi^s_t \geq \beta \delta \mathbb{E}_t \max \{ p_{t+1} \phi^m_{t+1}, \phi^s_{t+1} \}, \text{ with } "= " \text{ if } \tilde{a}^s_{dt+1} > 0 \]  
(35)

\[ \phi^m_t \geq \beta \mathbb{E}_t \left[ \phi^m_{t+1} + \alpha \theta \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} (\varepsilon - \varepsilon^*_{t+1}) y_{t+1} dG(\varepsilon) \frac{1}{p_{t+1}} \right], \text{ with } "= " \text{ if } \tilde{a}^m_{dt+1} > 0 \]  
(36)

\[ \phi^s_t \geq \beta \delta \mathbb{E}_t \left[ \varepsilon y_{t+1} + \phi^s_{t+1} + \alpha \theta \int_{\varepsilon_L}^{\varepsilon^*_{t+1}} (\varepsilon^*_{t+1} - \varepsilon) y_{t+1} dG(\varepsilon) \right], \text{ with } "= " \text{ if } \tilde{a}^s_{dt+1} > 0. \]  
(37)

**Proof.** With Lemma 1, we can write \( V'^I_t (a_t, \varepsilon) \) as

\[
V'^I_t (a_t, \varepsilon) = \left[ \alpha \theta (\varepsilon - \varepsilon^*_{t}) I_{\{\varepsilon^*_{t} < \varepsilon\}} \frac{1}{p_t} y_t + \phi^m_t \right] a^m_t
\]

\[
+ \left\{ \varepsilon + \alpha \theta (\varepsilon^*_{t} - \varepsilon) I_{\{\varepsilon^*_{t} < \varepsilon\}} \right\} y_t + \phi^s_t \}
\]

\[ a^s_t + W^I_t \]  
(38)

and \( V'^D_t (a_t) \) as

\[ V'^D_t (a_t) = \alpha \int k_t (a_{it}, \varepsilon) dH_{It} (a_{it}, \varepsilon) + \max \{ \phi^m_t, \phi^s_t/p_t \} (a^m_t + p_t a^s_t) + W^D_t. \]

Since \( \varepsilon \) is i.i.d. over time, \( W'^I_t (a_t) \) is independent of \( \varepsilon \) and the portfolio that each investor chooses to carry into period \( t + 1 \) is independent of \( \varepsilon \). Therefore we can write \( dH_{It} (a_t, \varepsilon) = dF_{It} (a_t) dG(\varepsilon) \), where \( F_{It} \) is the joint cumulative distribution function of investors’ money and equity holdings at the beginning of the OTC round of period-\( t \). Thus

\[ V'^D_t (a_t) = \max \{ \phi^m_t, \phi^s_t/p_t \} (a^m_t + p_t a^s_t) + V'^D_t (0) \]  
(39)

where

\[ V'^D_t (0) = \alpha \left( 1 - \theta \right) \int (\varepsilon - \varepsilon^*_{t}) \left[ I_{\{\varepsilon^*_{t} < \varepsilon\}} \frac{1}{p_t} A^m_{It} - I_{\{\varepsilon < \varepsilon^*_{t}\}} A^s_{It} \right] dG(\varepsilon) y_t + W^D_t. \]

From (39) we have

\[ V'^D_{t+1} (\tilde{a}^m_{t+1}, \delta \tilde{a}^s_{t+1}) = \max \{ \phi^m_{t+1}, \phi^s_{t+1}/p_{t+1} \} (\tilde{a}^m_{t+1} + p_{t+1} \delta \tilde{a}^s_{t+1}) + V'^D_{t+1} (0) \]

and from (38) we have

\[
\int V'^I_{t+1} [\tilde{a}^m_{t+1}, \delta \tilde{a}^s_{t+1} + (1 - \delta) A^s, \varepsilon] = \left[ \alpha \theta \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} dG(\varepsilon) \frac{1}{p_{t+1}} y_{t+1} + \phi^m_{t+1} \right] \tilde{a}^m_{t+1}
\]

\[
+ \delta \left[ \varepsilon + \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} \alpha \theta (\varepsilon - \varepsilon^*_{t+1} - \varepsilon) dG(\varepsilon) y_{t+1} + \phi^s_{t+1} \right] \tilde{a}^s_{t+1} + \zeta_{t+1}
\]

46
where \( \zeta_{t+1} \equiv \left\{ \varepsilon + \alpha \theta \left( \varepsilon_{t+1}^* - \varepsilon \right) \mathbb{I}_{\{\varepsilon < \varepsilon_{t+1}^*\}} \right\} y_{t+1} + \phi_{t+1}^* \right\} (1 - \delta)^t A^s + W_{t+1}^f. \) Thus the necessary and sufficient first-order conditions corresponding to the maximization problems in (30) and (33) are as in the statement of the lemma. ■

**Lemma 3** In period \( t \), the interdealer market clearing condition for equity is

\[
\{\alpha [1 - G(\varepsilon_t^*)] A_{Dt}^m + \chi (\varepsilon_t^*, 0) A_{Dt}^p \} \frac{1}{p_t} = \alpha G(\varepsilon_t^*) A_{It}^s + [1 - \chi (\varepsilon_t^*, 0)] A_{It}^f. \tag{40}
\]

**Proof.** Recall \( \bar{A}_{Dt}^s = \int \bar{a}_t^s (a_t) dF_{Dt} (a_t) \), so from Lemma 1, we have

\[
\bar{A}_{Dt}^s = \chi (\varepsilon_t^*, 0) (A_{Dt}^s + A_{Dt}^p/p_t).
\]

Similarly, \( \bar{A}_{It}^s = \alpha \int \bar{a}_t^s (a_t, \varepsilon) dH_{It} (a_t, \varepsilon) \), so from Lemma 1, we have

\[
\bar{A}_{It}^s = \alpha [1 - G(\varepsilon_t^*)] (A_{It}^s + A_{It}^p/p_t).
\]

With these expressions, the market-clearing condition for equity in the interdealer market of period \( t \), i.e., \( \bar{A}_{Dt}^s + \bar{A}_{It}^s = A_{Dt}^s + \alpha A_{It}^s \), can be written as in the statement of the lemma. ■

**Corollary 2** A sequence of prices, \( \{1/p_t, \phi_t^m, \phi_t^s\}_{t=0}^{\infty} \), together with bilateral terms of trade in the OTC market, \( \{\bar{a}_t, k_t\}_{t=0}^{\infty}, \) dealer portfolios, \( \{(\bar{a}_{dt}, \bar{a}_{dt+1}, a_{dt+1})_{d \in D}\}_{t=0}^{\infty}, \) and investor portfolios, \( \{(\bar{a}_{it+1}, a_{it+1})_{i \in I}\}_{t=0}^{\infty}, \) constitute an equilibrium if and only if they satisfy the following conditions for all \( t \):

(i) **Intermediation fee and optimal post-trade portfolios in OTC market**

\[
k_t (a_t, \varepsilon) = (1 - \theta) (\varepsilon - \varepsilon_t^*) \left[ \chi (\varepsilon_t^*, \varepsilon) \frac{1}{p_t} a_t^m - [1 - \chi (\varepsilon_t^*, \varepsilon)] a_t^s \right] y_t
\]

\[
\bar{a}_t^m (a_t, \varepsilon) = [1 - \chi (\varepsilon_t^*, \varepsilon)] (a_t^m + p_t a_t^s)
\]

\[
\bar{a}_t^s (a_t, \varepsilon) = \chi (\varepsilon_t^*, \varepsilon) (1/p_t) (a_t^m + p_t a_t^s)
\]

\[
\bar{a}_t (a_t) = \bar{a}_t (a_t, 0).
\]

(ii) **Interdealer market clearing**

\[
\{\alpha [1 - G(\varepsilon^*)] A_{Dt}^m + \chi (\varepsilon_t^*, 0) A_{Dt}^p \} \frac{1}{p_t} = \alpha G(\varepsilon^*) A_{It}^s + [1 - \chi (\varepsilon^*, 0)] A_{It}^f
\]

where \( A_{Dt}^m \equiv \int a_t^m dF_{Dt} (a_t) \) and \( A_{It}^s \equiv \int a_t^s dF_{It} (a_t) \) for \( j \in \{D, I\}. \)
(iii) Optimal end-of-period portfolios:

\[
\phi^m_t \geq \beta \mathbb{E}_t \max \left( \phi^m_{t+1}, \phi^s_{t+1}/p_{t+1} \right)
\]

\[
\phi^s_t \geq \beta \delta \mathbb{E}_t \max \left( p_{t+1} \phi^m_{t+1}, \phi^s_{t+1} \right)
\]

\[
\phi^m_t \geq \beta \mathbb{E}_t \left[ \phi^m_{t+1} + \alpha \theta \frac{1}{p_{t+1}} \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} (\varepsilon - \varepsilon^*_{t+1}) G(\varepsilon) \, d\varepsilon \right]
\]

\[
\phi^s_t \geq \beta \delta \mathbb{E}_t \left[ \bar{\varepsilon} y_{t+1} + \phi^s_{t+1} + \alpha \theta \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} (\varepsilon^*_{t+1} - \varepsilon) y_{t+1} G(\varepsilon) \right]
\]

with

\[
\left[ \phi^m_t - \beta \mathbb{E}_t \max \left( \phi^m_{t+1}, \phi^s_{t+1}/p_{t+1} \right) \right] \tilde{\alpha}^m_{dt+1} = 0
\]

\[
\left[ \phi^s_t - \beta \delta \mathbb{E}_t \max \left( p_{t+1} \phi^m_{t+1}, \phi^s_{t+1} \right) \right] \tilde{\alpha}^s_{dt+1} = 0
\]

\[
\left\{ \phi^m_t - \beta \mathbb{E}_t \left[ \phi^m_{t+1} + \alpha \theta \frac{1}{p_{t+1}} \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} (\varepsilon - \varepsilon^*_{t+1}) G(\varepsilon) \, d\varepsilon \right] \right\} \tilde{\alpha}^m_{dt+1} = 0
\]

\[
\left\{ \phi^s_t - \beta \delta \mathbb{E}_t \left[ \bar{\varepsilon} y_{t+1} + \phi^s_{t+1} + \alpha \theta \int_{\varepsilon^*_{t+1}}^{\varepsilon_{t+1}} (\varepsilon^*_{t+1} - \varepsilon) y_{t+1} G(\varepsilon) \right] \right\} \tilde{\alpha}^s_{dt+1} = 0
\]

for all \( d \in \mathcal{D} \) and all \( i \in \mathcal{I} \), and

\[
a^m_{jt+1} = \tilde{\alpha}^m_{jt+1}
\]

\[
a^s_{jt+1} = \delta \tilde{\alpha}^s_{jt+1} + I_{(j \in \mathcal{I})} (1 - \delta) A^s
\]

\[
\tilde{\alpha}^k_{jt+1} \in \mathbb{R}_+ \text{ for } k \in \{s,m\}
\]

for all \( d \in \mathcal{D} \cup \mathcal{I} \).

(iv) End-of-period market clearing

\[
\tilde{A}^s_{Dt+1} + \tilde{A}^s_{It+1} = A^s
\]

\[
\tilde{A}^m_{Dt+1} + \tilde{A}^m_{It+1} = A^m_{t+1}
\]

where \( \tilde{A}^k_{Dt+1} \equiv \int_{\mathcal{D}} \tilde{a}^k_{zt+1} \, dx \) and \( \tilde{A}^k_{It+1} \equiv \int_{\mathcal{I}} \tilde{a}^k_{zt+1} \, dx \) for \( k \in \{s,m\} \).

**Proof.** Follows immediately from Definition 1 together with Lemma 1, Lemma 2, and Lemma 3. ■

**Lemma 4** Consider \( \hat{\mu} \) and \( \bar{\mu} \) as defined in (10). Then \( \hat{\mu} < \bar{\mu} \).
Proof of Lemma 4. Define Υ (ζ) : \( \mathbb{R} \rightarrow \mathbb{R} \) by Υ (ζ) \( \equiv \beta \left[ 1 + \alpha \theta (1 - \beta \delta) \zeta \right] \). Let \( \hat{\zeta} \equiv \frac{(1 - \alpha \theta(\zeta - \bar{\epsilon}))}{\alpha \theta} \) and \( \bar{\zeta} \equiv \frac{\bar{\zeta}}{\beta \delta \bar{\epsilon} + (1 - \beta \delta) \bar{\epsilon}} \), so that \( \hat{\mu} = \Upsilon(\hat{\zeta}) \) and \( \bar{\mu} = \Upsilon(\bar{\zeta}) \). Since \( \Upsilon \) is strictly increasing, \( \hat{\mu} < \bar{\mu} \) if and only if \( \hat{\zeta} < \bar{\zeta} \). With (11) and the fact that \( \bar{\epsilon} \equiv \int_{\bar{\epsilon}}^{\epsilon} H(\epsilon) dG(\epsilon) = \epsilon - \int_{\bar{\epsilon}}^{\epsilon} G(\epsilon) d\bar{\epsilon} \),

\[
\hat{\zeta} = \int_{\bar{\epsilon}}^{\epsilon} \frac{[1 - G(\epsilon)] d\epsilon}{\bar{\epsilon} + \alpha \theta \int_{\bar{\epsilon}}^{\epsilon} G(\epsilon) d\bar{\epsilon}},
\]
so clearly,

\[
\hat{\zeta} < \int_{\bar{\epsilon}}^{\epsilon} \frac{[1 - G(\epsilon)] d\epsilon}{\bar{\epsilon}} = \frac{\bar{\epsilon} - \epsilon}{\bar{\epsilon}} < \bar{\zeta}.
\]
Hence \( \hat{\mu} < \bar{\mu} \). ■

Proof of Proposition 2. In an equilibrium with no money (or no valued money), there is no trade in the OTC market. From Lemma 2, the first-order conditions for a dealer \( d \in D \) and an investor \( i \in I \) in the time-\( t \) Walrasian market are

\[
\phi_t^{s} \geq \beta \delta \mathbb{E}_t \phi_{t+1}^{s}, \quad " = " \text{ if } \bar{a}_{t+1}^{s} > 0
\]

\[
\phi_t^{s} \geq \beta \delta \mathbb{E}_t \left( \bar{\epsilon} y_{t+1} + \phi_{t+1}^{s} \right), \quad " = " \text{ if } \bar{a}_{t+1}^{i} > 0.
\]

In a stationary equilibrium, \( \mathbb{E}_t (\phi_{t+1}^{s} / \phi_t^{s}) = \gamma \), and \( \beta \delta \gamma < 1 \) is a maintained assumption, so no dealer holds equity. The Walrasian market for equity can only clear if \( \phi_t^{s} = \bar{\beta} \bar{\delta} \bar{\epsilon} \). This establishes parts (i) and (iii) in the statement of the proposition.

Next, we turn to monetary equilibria. In a stationary equilibrium the Euler equations (34)-(37) become

\[
\mu \geq \bar{\beta}, \quad " = " \text{ if } \bar{a}_{dt+1}^{m} > 0 \quad (41)
\]

\[
\phi^{s} \geq \beta \delta \bar{\phi}^{s}, \quad " = " \text{ if } \bar{a}_{dt+1}^{s} > 0 \quad (42)
\]

\[
1 \geq \frac{\bar{\beta}}{\mu} \left[ 1 + \frac{\alpha \theta}{\epsilon^* + \phi^{s} \int_{\epsilon^*}^{\bar{\epsilon}} (\epsilon - \epsilon^*) dG(\epsilon) \right], \quad " = " \text{ if } \bar{a}_{dt+1}^{m} > 0 \quad (43)
\]

\[
\phi^{s} \geq \frac{\bar{\beta} \delta}{1 - \beta \delta} \left[ \bar{\epsilon} + \alpha \theta \int_{\epsilon^*}^{\bar{\epsilon}} (\epsilon^* - \epsilon^*) dG(\epsilon) \right], \quad " = " \text{ if } \bar{a}_{dt+1}^{s} > 0. \quad (44)
\]

(We have used the fact that, as will become clear below, \( \bar{\phi}^{s} \equiv \epsilon^* + \phi^{s} \geq \epsilon_L + \phi^{s} > \phi^{s} \) in any equilibrium.) Under our maintained assumption \( \bar{\beta} < \mu \) , (41) implies \( \bar{a}_{dt+1}^{m} = Z_D = 0 \), so (43) must hold with equality for some investor in a monetary equilibrium. Thus, in order to find a monetary equilibrium there are three possible equilibrium configurations to consider.
depending on the binding patterns of the complementary slackness conditions associated with (42) and (44). The interdealer market-clearing condition, \( \bar{A}_{Dt}^s + \bar{A}_{It}^s = A_{Dt}^s + \alpha A_{It}^s \), must hold for all three configurations. Lemma 3 shows that this condition is equivalent to (40) and in a stationary equilibrium (40) reduces to

\[
Z = \frac{\varepsilon^* + \phi^s}{\alpha [1 - G(\varepsilon^*)]} \{ \alpha G(\varepsilon^*) A_I^s + [1 - \chi(\varepsilon^*, 0)] A_D^s \}.
\]

This condition in turn reduces to (17) if, as shown below, the equilibrium has \( 0 < \varepsilon^* \). The rest of the proof proceeds in three steps.

Step 1: Try to construct a stationary monetary equilibrium with \( \tilde{a}_{dt+1}^s = 0 \) for all \( d \in D \) and \( \tilde{a}_{it+1}^s > 0 \) for some \( i \in I \). The equilibrium conditions for this case are (17) together with

\[
\phi^s > \frac{\tilde{a}_{dt+1}^s}{\phi^s} = \beta \delta \phi^s, \tag{45}
\]

\[
1 = \frac{\tilde{a}_{dt+1}^s}{\mu} \left[ 1 + \frac{\alpha \theta}{\varepsilon^* + \phi^s} \int_{\varepsilon^*}^{\tilde{a}_{dt+1}^s} (\varepsilon - \varepsilon^*) dG(\varepsilon) \right], \tag{46}
\]

\[
\phi^s = \frac{\beta \delta}{1 - \beta \delta} \left[ \bar{\varepsilon} + \alpha \theta \int_{\varepsilon^*}^{\tilde{a}_{dt+1}^s} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right], \tag{47}
\]

and

\[
\tilde{a}_{dt+1}^m = 0 \quad \text{for all} \quad d \in D, \tag{48}
\]

\[
\tilde{a}_{it+1}^m \geq 0, \quad \text{with} \quad " > " \quad \text{for some} \quad i \in I, \tag{49}
\]

\[
\tilde{a}_{dt+1}^s = 0 \quad \text{for all} \quad d \in D, \tag{50}
\]

\[
\tilde{a}_{it+1}^s \geq 0, \quad \text{with} \quad " > " \quad \text{for some} \quad i \in I. \tag{51}
\]

Conditions (46) and (47) are to be solved for the two unknowns \( \varepsilon^* \) and \( \phi^s \). Substitute (47) into (46) to obtain

\[
1 = \frac{\beta}{\mu} \left[ 1 + \frac{\alpha \theta}{\varepsilon^* + \phi^s} \int_{\varepsilon^*}^{\tilde{a}_{dt+1}^s} (\varepsilon - \varepsilon^*) dG(\varepsilon) \right], \tag{52}
\]

which is a single equation in \( \varepsilon^* \). Define

\[
T(x) \equiv \frac{\int_{x}^{\varepsilon^*} (\varepsilon - x) dG(\varepsilon)}{1 - \beta \delta} \left[ \bar{\varepsilon} + \alpha \theta \int_{\varepsilon^*}^{x} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right] - \frac{\mu - \bar{\beta}}{\beta \alpha \theta} \tag{53}
\]

with

\[
\hat{T}(x) \equiv \bar{\varepsilon} - x + \alpha \theta \int_{\varepsilon^*}^{x} (x - \varepsilon) dG(\varepsilon), \tag{54}
\]

50
and notice that \( \varepsilon^* \) solves (52) if and only if it satisfies \( T(\varepsilon^*) = 0 \). \( T \) is a continuous real-valued function on \( [\varepsilon_L, \varepsilon_H] \), with

\[
T(\varepsilon_L) = \frac{\varepsilon - \varepsilon_L}{\varepsilon_L + \frac{\beta \delta}{1 - \beta \delta}} - \frac{\mu - \beta}{\beta \alpha \theta},
\]

\[
T(\varepsilon_H) = -\frac{\mu - \beta}{\beta \alpha \theta} < 0,
\]

and

\[
T'(x) = -\frac{[1 - G(x)]\left\{x + \frac{\beta \delta}{1 - \beta \delta} [\varepsilon + \alpha \theta f_{t_L}^x G(\varepsilon) d \varepsilon]\right\} + [f_{x_L}^{e_H} [1 - G(\varepsilon)] d \varepsilon\left\{1 + \frac{\beta \delta}{1 - \beta \delta} \alpha \theta G(\varepsilon)\right\}]}{\left\{x + \frac{\beta \delta}{1 - \beta \delta} [\varepsilon + \alpha \theta f_{t_L}^x G(\varepsilon) d \varepsilon]\right\}^2} < 0.
\]

Hence if \( T(\varepsilon_L) > 0 \), or equivalently, if \( \mu < \bar{\mu} \) (with \( \bar{\mu} \) is as defined in (10)) then there exists a unique \( \varepsilon^* \in (\varepsilon_L, \varepsilon_H) \) that satisfies \( T(\varepsilon^*) = 0 \) (and \( \varepsilon^* \downarrow \varepsilon_L \) as \( \mu \uparrow \bar{\mu} \)). Once we know \( \varepsilon^* \), \( \phi^* \) is given by (47). Given \( \varepsilon^* \) and \( \phi^* \), the values of \( Z, \tilde{\phi}^*, \phi_{t_{-1}}^* \) and \( p_t \) are obtained using (17) (with \( A_{t_1}^* = A^* \) and \( A_{t_{-1}}^* = 0 \)), (14), (15) and (16). To conclude this step notice that for this case to be an equilibrium, (45) must hold, or equivalently, using \( \phi^* = \varepsilon^* + \phi^* \) and (47), it must be that \( \hat{T}(\varepsilon^*) > 0 \), where \( \hat{T} \) is the continuous function on \( [\varepsilon_L, \varepsilon_H] \) defined in (54). Notice that \( \hat{T}'(x) = -[1 - \alpha \theta G(x)] < 0 \), and \( \hat{T}(\varepsilon_H) = -(1 - \alpha \theta)(\varepsilon_H - \bar{\varepsilon}) < 0 < \bar{\varepsilon} - \varepsilon_L = \hat{T}(\varepsilon_L) \), so there exists a unique \( \hat{\varepsilon} \in (\varepsilon_L, \varepsilon_H) \) such that \( \hat{T}(\hat{\varepsilon}) = 0 \). (Since \( \hat{T}(\varepsilon) > 0 \), and \( \hat{T}' < 0 \), it follows that \( \bar{\varepsilon} < \hat{\varepsilon} \)). Then \( \hat{T}'(x) < 0 \) implies \( \hat{T}(\varepsilon^*) \geq 0 \) if and only if \( \varepsilon^* \leq \hat{\varepsilon} \), with \( = \) for \( \varepsilon^* = \hat{\varepsilon} \). With (53), we know that \( \varepsilon^* < \hat{\varepsilon} \) if and only if \( T(\hat{\varepsilon}) < 0 = T(\varepsilon^*) \), i.e., if and only if

\[
\beta \left[ 1 + \frac{(1 - \beta \delta) \alpha \theta \int_{\varepsilon_L}^{e_H} (\varepsilon - \hat{\varepsilon}) d G(\varepsilon)}{\hat{\varepsilon}} \right] < \mu.
\]

Since \( \hat{T}(\varepsilon) = -(1 - \alpha \theta)(\varepsilon - \bar{\varepsilon}) + \alpha \theta \int_{\varepsilon_L}^{e_H} (\varepsilon - \hat{\varepsilon}) d G(\varepsilon) = 0 \), this last condition is equivalent to \( \bar{\mu} < \mu \), where \( \bar{\mu} \) is as defined in (10). The allocations and asset prices described in this step correspond to those in the statement of the proposition for \( \mu \in (\bar{\mu}, \bar{\mu}) \).

Step 2: Try to construct a stationary monetary equilibrium with \( a_{dt+1}^* > 0 \) for some \( d \in D \), and \( a_{dt+1}^* = 0 \) for all \( i \in I \). The equilibrium conditions are (17), (46), (48), (49), together with

\[
\phi^* = \beta \delta \tilde{\phi}^*
\]

(55)

\[
\phi^* > \frac{\beta \delta}{1 - \beta \delta} \left[ \varepsilon + \alpha \theta \int_{\varepsilon_L}^{e_H} (\varepsilon - \hat{\varepsilon}) d G(\varepsilon) \right], \text{ "} = \text{ " if } \tilde{a}_{dt+1}^* > 0.
\]

(56)

\[
\tilde{a}_{dt+1}^* \geq 0, \text{ with } " > " \text{ for some } d \in D
\]

(57)

\[
\tilde{a}_{dt+1}^* = 0, \text{ for all } i \in I.
\]

(58)
The conditions (46) and (55) are to be solved for \( \varepsilon^* \) and \( \phi^s \). First use \( \bar{\phi}^s = \varepsilon^* + \phi^s \) in (55) to obtain
\[
\phi^s = \frac{\bar{\beta}\delta}{1 - \beta\delta} \varepsilon^*.
\]
(59)

Substitute (59) in (46) to obtain
\[
1 = \frac{\bar{\beta}}{\mu} \left[ 1 + \frac{\alpha \theta (1 - \bar{\beta}\delta) \int_{\varepsilon^*}^{\varepsilon^H} (\varepsilon - \varepsilon^*) \, dG(\varepsilon)}{\varepsilon^*} \right]
\]
(60)
which is a single equation in \( \varepsilon^* \). Define
\[
R(x) \equiv \frac{(1 - \bar{\beta}\delta) (\bar{\varepsilon} - x)}{x} - \frac{\mu - \bar{\beta}}{\beta\alpha\theta}
\]
(61)
and notice that \( \varepsilon^* \) solves (60) if and only if it satisfies \( R(\varepsilon^*) = 0 \). \( R \) is a continuous real-valued function on \( [\varepsilon_L, \varepsilon_H] \), with
\[
R(\varepsilon_L) = \frac{(1 - \bar{\beta}\delta) (\bar{\varepsilon} - \varepsilon_L)}{\varepsilon_L} - \frac{\mu - \bar{\beta}}{\beta\alpha\theta}
\]
\[
R(\varepsilon_H) = -\frac{\mu - \bar{\beta}}{\beta\alpha\theta}
\]
and
\[
R'(x) = -[1 - G(x)] x + \int_x^{\varepsilon^H} [1 - G(\varepsilon)] \, d\varepsilon \frac{1}{1 - \beta x^2} < 0.
\]

Hence if \( R(\varepsilon_L) > 0 \), or equivalently, if
\[
\mu < \bar{\beta} \left[ 1 + \frac{\alpha \theta (1 - \bar{\beta}\delta) (\bar{\varepsilon} - \varepsilon_L)}{\varepsilon_L} \right] \equiv \mu^o
\]
then there exists a unique \( \varepsilon^* \in (\varepsilon_L, \varepsilon_H) \) that satisfies \( R(\varepsilon^*) = 0 \) (and \( \varepsilon^* \downarrow \varepsilon_L \) as \( \mu \uparrow \mu^o \)). Having solved for \( \varepsilon^* \), \( \phi^s \) is obtained from (59). Given \( \varepsilon^* \) and \( \phi^s \), the values of \( Z \), \( \bar{\phi}^s \), \( \phi^m_t \) and \( p_t \) are obtained using (17) (with \( A^s_D = A^s - A^s_I = \delta A^s \)), (14), (15) and (16). Notice that for this case to be an equilibrium (56) must hold, or equivalently, using (59), it must be that \( \hat{T}(\varepsilon^*) < 0 \), which is in turn equivalent to \( \hat{\varepsilon} < \varepsilon^* \). With (61), we know that \( \hat{\varepsilon} < \varepsilon^* \) if and only if \( R(\varepsilon^*) = 0 < R(\hat{\varepsilon}) \), i.e., if and only if
\[
\mu < \bar{\beta} \left[ 1 + \frac{\alpha \theta (1 - \bar{\beta}\delta) (\hat{\varepsilon} - \varepsilon_L)}{\varepsilon_L} \right]
\]
which using \( \hat{T}(\hat{\varepsilon}) = 0 \) can be written as \( \mu < \hat{\mu} \). To summarize, the prices and allocations constructed in this step constitute a stationary monetary equilibrium provided \( \mu \in (\bar{\beta}, \min (\hat{\mu}, \mu^o)) \).
To conclude this step, we show that \( \hat{\mu} < \bar{\mu} < \mu^o \), which together with the previous step will mean that there is no stationary monetary equilibrium for \( \mu \geq \bar{\mu} \) (thus establishing part (ii) in the statement of the proposition). It is clear that \( \bar{\mu} < \mu^o \), and we know that \( \hat{\mu} < \bar{\mu} \) from Lemma 4. Therefore the allocations and asset prices described in this step correspond to those in the statement of the proposition for the case with \( \mu \in (\bar{\beta}, \min (\hat{\mu}, \mu^o)) = (\bar{\beta}, \hat{\mu}) \).

Step 3: Try to construct a stationary monetary equilibrium with \( \tilde{a}_{it+1}^s > 0 \) for some \( d \in D \), and \( \tilde{a}_{it+1}^d > 0 \) for some \( i \in I \). The equilibrium conditions are (17), (46), (47), (48), (49), and (55) with

\[
\tilde{a}_{it+1}^s \geq 0 \text{ and } \tilde{a}_{it+1}^d \geq 0, \text{ with } " > " \text{ for some } i \in I \text{ or some } d \in I.
\]

Notice that \( \varepsilon^* \) and \( \phi^* \) are obtained as in Step 2. Now, however, (47) must also hold, which together with (59) implies we must have \( \tilde{T} (\varepsilon^*) = 0 \), or equivalently, \( \varepsilon^* = \tilde{\varepsilon} \). In other words, this condition requires \( R (\tilde{\varepsilon}) = \tilde{T} (\tilde{\varepsilon}) \), or equivalently, we must have \( \mu = \hat{\mu} \). As before, the market-clearing condition (17) is used to obtain \( Z \), while (14), (15), and (16) imply \( \tilde{\phi}^s, \tilde{\phi}^d, \text{ and } p_t \), respectively. The allocations and asset prices described in this step correspond to those in the statement of the proposition for the case with \( \mu = \hat{\mu} \).

Combined, Steps 1, 2, and 3 prove part (iv) in the statement of the proposition. Part (v)(a) is immediate from (47) and (53), and part (v)(b) from (59) and (61).

**Corollary 3** The marginal type, \( \varepsilon^* \), characterized in Proposition 2 is strictly decreasing in the rate of inflation, i.e., \( \partial \varepsilon^*/\partial \mu < 0 \) both for \( \mu \in (\bar{\beta}, \hat{\mu}) \), and for \( \mu \in (\hat{\mu}, \bar{\mu}) \).

**Proof of Corollary 3.** For \( \mu \in (\bar{\beta}, \hat{\mu}) \), implicitly differentiate \( R (\varepsilon^*) = 0 \) (with \( R \) given by (61)), and for \( \mu \in (\hat{\mu}, \bar{\mu}) \), implicitly differentiate \( T (\varepsilon^*) = 0 \) (with \( T \) given by (53)) to obtain

\[
\frac{\partial \varepsilon^*}{\partial \mu} = \begin{cases} 
- \frac{\tilde{\beta} \alpha \theta (1-\tilde{\beta})[1-G(\varepsilon^*)]+\mu-\tilde{\beta}}{\tilde{\beta} \alpha \theta [T(\varepsilon^*)^2(1-G(\varepsilon^*))]} & \text{if } \bar{\beta} < \mu < \hat{\mu} \\
- \frac{1+\tilde{\beta} \alpha \theta \left( \frac{\alpha \theta G (\varepsilon^*)}{1-\tilde{\beta}} + \frac{1-G(\varepsilon^*)}{\mu-\tilde{\beta}} \right) (\mu-\beta)^2}{\tilde{\beta} \alpha \theta [T(\varepsilon^*)^2(1-G(\varepsilon^*))]} & \text{if } \hat{\mu} < \mu < \bar{\mu}.
\end{cases}
\]

Clearly, \( \partial \varepsilon^*/\partial \mu < 0 \) for \( \mu \in (\bar{\beta}, \hat{\mu}) \), and for \( \mu \in (\hat{\mu}, \bar{\mu}) \).

**Proof of Proposition 3.** Recall that \( \partial \varepsilon^*/\partial \mu < 0 \) (Corollary 3). (i) From (13),

\[
\frac{\partial \phi^*}{\partial \mu} = \frac{\tilde{\beta} \delta}{1-\beta \delta} \left( I_{\beta < \mu \leq \hat{\mu}} + I_{\mu < \mu < \bar{\mu}} \alpha \theta G (\varepsilon^*) \right) \frac{\partial \varepsilon^*}{\partial \mu} < 0
\]

and from (19), \( \partial \phi^*/\partial t = \tilde{\beta} \partial \phi^*/\partial \mu < 0 \). (ii) Condition (14) implies \( \partial \tilde{\phi}^s/\partial \mu = \partial \varepsilon^*/\partial \mu + \partial \phi^s/\partial \mu < 0 \). (iii) From (17) it is clear that \( \partial Z/\partial \varepsilon^* > 0 \), so \( \partial Z/\partial \mu = (\partial Z/\partial \varepsilon^*)(\partial \varepsilon^*/\partial \mu) < 0 \). From (15), \( \partial \phi^m_\mu/\partial \mu = (\eta_t/A^m) \partial Z/\partial \mu < 0 \).
Proof of Proposition 4. From condition (18),
\[
\frac{\partial \varepsilon^*}{\partial (\alpha \theta)} = \frac{\mu - \tilde{\beta} E[\varepsilon^* + \beta \delta (\varepsilon^* - \varepsilon^0)]}{\beta \alpha (1 - \beta \delta) [1 - G(\varepsilon^*)] + (\mu - \beta) \left\{1 + \beta \delta [\alpha \theta G(\varepsilon^*) - 1] \right\}} > 0. \tag{62}
\]
(i) From (13),
\[
\frac{\partial \delta^*}{\partial (\alpha \theta)} = \begin{cases} \frac{\beta}{1 - \beta \delta} \frac{\partial \varepsilon^*}{\partial (\alpha \theta)} > 0 & \text{if } \tilde{\beta} < \mu \leq \tilde{\mu} \\
\beta \beta \delta \left[\int_{\varepsilon_L} G(\varepsilon) d\varepsilon + \alpha \theta G(\varepsilon^*) \frac{\partial \varepsilon^*}{\partial (\alpha \theta)} \right] > 0 & \text{if } \tilde{\mu} < \mu < \tilde{\beta} .
\end{cases}
\]
(ii) From (14), \(\partial \tilde{\delta}/\partial (\alpha \theta) = \partial \varepsilon^*/\partial (\alpha \theta) + \partial \delta^* / \partial (\alpha \theta) > 0\). (iii) For \(\mu \in (\tilde{\mu}, \tilde{\beta})\), (17) implies \(\partial Z/\partial \alpha = (\partial Z/\partial \varepsilon^*) (\partial \varepsilon^*/\partial (\alpha \theta)) > 0\) and therefore \(\partial \phi^m / \partial \alpha = (\partial Z/\partial \alpha) (y_i / A_i^m) > 0\).

Proof of Proposition 5. (i) The result is immediate from the expression for \(A_i^D\) in Proposition 2. (ii) From (10) and (11),
\[
\frac{\partial \mu}{\partial (\alpha \theta)} = \beta \left(1 - \beta \delta \right) \left\{\frac{(1 - \alpha \theta) \varepsilon}{[1 - \alpha \theta G(\varepsilon)]} \int_{\varepsilon_L} \left(1 + \beta \delta - \frac{\varepsilon}{\varepsilon^*} \right) G(\varepsilon) d\varepsilon - \tilde{\varepsilon} \right\} .
\]
Notice that \(\partial \mu / \partial (\alpha \theta)\) approaches a positive value as \(\alpha \theta \to 0\), and a negative value as \(\alpha \theta \to 1\). Also, \(\mu \to \tilde{\beta}\) both when \(\alpha \theta \to 0\), and when \(\alpha \theta \to 1\). Hence \(\mu / \beta \to \lim_{\alpha \theta \to 0} \tilde{\mu} = \lim_{\alpha \theta \to 1} \tilde{\mu}\) for a range of values of \(\alpha \theta\) close to 0 and a range of values of \(\alpha \theta\) close to 1. For those ranges of values of \(\alpha \theta\), \(A_i^D = 0\). In between those ranges there must exist values of \(\alpha \theta\) such that \(\mu < \tilde{\mu}\) which implies \(A_i^D > 0\).

Proof of Proposition 6. (i) Differentiate (20) to get
\[
\frac{\partial \mathcal{V}}{\partial \mu} = 2\alpha G'(\varepsilon^*) (A^b - \delta A_i^b) \frac{\partial \varepsilon^*}{\partial \mu} < 0,
\]
where the inequality follows from Corollary 3. Also, from (19), \(\partial \mathcal{V} / \partial \varepsilon = \tilde{\beta} \partial \mathcal{V} / \partial \varepsilon < 0\). (ii) From (20),
\[
\frac{\partial \mathcal{V}}{\partial \theta} = 2 \alpha G'(\varepsilon^*) (A^b - \delta A_i^b) \frac{\partial \varepsilon^*}{\partial \theta} \frac{\partial \varepsilon^*}{\partial \alpha} (A^b - \delta A_i^b)
\]
and both are positive since \(\partial \varepsilon^*/\partial (\alpha \theta) > 0\) (see (62)).

Proof of Proposition 7. (i) For \(\tilde{\beta} < \mu \leq \tilde{\mu}\), \(\partial \mathcal{P} / \partial \mu = [\tilde{\beta} \delta / (1 - \beta \delta)] (\partial \varepsilon^*/\partial \mu) \leq 0\), and for \(\tilde{\mu} < \mu < \mu\), \(\partial \mathcal{P} / \partial \mu = [\tilde{\beta} \delta / (1 - \beta \delta)] (\partial \varepsilon^*/\partial \mu) < 0\). In both cases, \(\partial \mathcal{P} / \partial \varepsilon = \tilde{\beta} \partial \mathcal{P} / \partial \varepsilon < 0\). (ii) For \(\tilde{\beta} < \mu \leq \tilde{\mu}\), \(\partial \mathcal{P} / \partial (\alpha \theta) = [\tilde{\beta} \delta / (1 - \beta \delta)] (\partial \varepsilon^*/\partial (\alpha \theta)) > 0\), and for \(\tilde{\mu} < \mu < \tilde{\mu}\), \(\partial \mathcal{P} / \partial \mu = [\tilde{\beta} \delta / (1 - \beta \delta)] (\partial \varepsilon^*/\partial (\alpha \theta)) + \int_{\varepsilon_L} G(\varepsilon) d\varepsilon > 0\).
B Supplementary material

B.1 VAR estimation

B.1.1 Identification

We conjecture that the data, \{Y_t\} with \(Y_t \in \mathbb{R}^n\), corresponds to an equilibrium that can be approximated by a structural vector autoregression (SVAR),

\[ KY_t = \sum_{j=1}^{J} C_j Y_{t-j} + \varepsilon_t, \quad (63) \]

where \(K\) and \(C_j\) are \(n \times n\) matrices, \(J \geq 1\) is an integer that denotes the maximum number of lags, and \(\varepsilon_t \in \mathbb{R}^n\) is a vector of structural shocks, with \(\mathbb{E}(\varepsilon_t) = 0\), \(\mathbb{E}(\varepsilon_t \varepsilon_t') = I\), and \(\mathbb{E}(\varepsilon_t \varepsilon_s') = 0\) for \(s \neq t\), where 0 is a conformable matrix of zeroes and \(I\) denotes the \(n\)-dimensional identity. If \(K\) is invertible, (63) can be represented by the reduced-form VAR

\[ Y_t = \sum_{j=1}^{J} B_j Y_{t-j} + u_t, \quad (64) \]

where \(B_j = K^{-1} C_j\) and

\[ u_t = K^{-1} \varepsilon_t \quad (65) \]

is an error term with

\[ \Xi \equiv \mathbb{E}(u_t u_t') = K^{-1} K^{-1}'. \quad (66) \]

The reduced-form VAR (64) can be estimated to obtain the matrices \(\{B_j\}_{j=1}^{J}\), and the residuals \(\{u_t\}\) from the estimation can be used to calculate \(\Xi\). From (65), we know that the disturbances of the reduced-form VAR (64) are linear combinations of the structural shocks, \(\varepsilon_t\), so in order to use (64) and the estimates \(\{B_j\}_{j=1}^{J}\) to compute the impulse responses to the structural shocks it is necessary to find the \(n^2\) elements of the matrix \(K^{-1}\). However, given the known covariance matrix \(\Xi\), (66) only provides \(n(n + 1)/2\) independent equations involving the elements of \(K^{-1}\), so \(n(n - 1)/2\) additional independent conditions would be necessary to find all elements of \(K^{-1}\). This is the well-known identification problem of the SVAR (63). Only three specific elements of \(K^{-1}\) are relevant for our analysis. To find them, we use an identification scheme that relies on external instruments.\(^36\)

\(^{36}\)The identification methodology has been used by Mertens and Ravn (2013), Stock and Watson (2012), Gertler and Karadi (2014), Hamilton (2003), and Kilian (2008a,b), among others.
The VAR we estimate consists of three variables, i.e., $Y_t = (i_t, R_t, T_t)'$, where $i_t$, $R_t$, and $T_t$ are the measures of the policy rate, the stock return, and turnover described in Sections 6.1 and 6.2. Denote $\varepsilon_t = (\varepsilon_i^t, \varepsilon_R^t, \varepsilon_T^t)'$, $u_t = (u_i^t, u_R^t, u_T^t)'$, and

$$K^{-1} = \begin{bmatrix} k_i^i & k_i^R & k_i^T \\ k_R^i & k_R^R & k_R^T \\ k_T^i & k_T^R & k_T^T \end{bmatrix}.$$ 

Then $u_t = K^{-1}\varepsilon_t$ can be written as

$$\begin{bmatrix} u_i^t \\ u_R^t \\ u_T^t \end{bmatrix} = \begin{bmatrix} k_i^i & k_i^R & k_i^T \\ k_R^i & k_R^R & k_R^T \\ k_T^i & k_T^R & k_T^T \end{bmatrix} \begin{bmatrix} \varepsilon_i^t \\ \varepsilon_R^t \\ \varepsilon_T^t \end{bmatrix} = \begin{bmatrix} k_i^i \varepsilon_i^t + \eta_i \\ k_i^R \varepsilon_R^t + \eta_R \\ k_i^T \varepsilon_T^t + \eta_T \end{bmatrix}$$.  \hspace{1cm} (67)

Since we are only interested in the impulse responses for the monetary shock, $\varepsilon_i^t$, it suffices to find the first column of $K^{-1}$. The identification problem we face, of course, stems from the fact that the structural shocks, $(\varepsilon_i^t, \varepsilon_R^t, \varepsilon_T^t)$, are unobservable and some of the elements of $K^{-1}$ are unknown (three elements are unknown in this $3 \times 3$ case). Suppose we had data on $\{\varepsilon_i^t\}$. Then we could run the regression $u_i^t = \kappa_i^i \varepsilon_i^t + \eta_i$ to estimate $\kappa_i^i$, where $\eta_i$ is an error term. From (67) we have $\eta_i = k_i^R \varepsilon_R^t + k_i^T \varepsilon_T^t$, so $\mathbb{E} (\varepsilon_i^t \eta_i) = \mathbb{E} [\varepsilon_i^t (k_i^R \varepsilon_R^t + k_i^T \varepsilon_T^t)] = 0$ (since we are assuming $\mathbb{E}(\varepsilon_i^t \varepsilon_i^t)' = I$), and thus the estimate of $\kappa_i^i$ could be used to identify $k_i^i$ (up to a constant) via the population regression of $u_i^t$ onto $\varepsilon_i^t$. Since $\varepsilon_i^t$ is unobservable, one natural alternative is to find a proxy (instrumental) variable for it. Suppose there is a variable $z_t$ such that

$$\mathbb{E} (z_i^t \varepsilon_i^t) = \mathbb{E} (z_i \varepsilon_i^T) = 0 < \mathbb{E} (z_i \varepsilon_i^t) \equiv v$$ for all $t$.

Then

$$\Lambda \equiv \mathbb{E}(z_t u_t) = K^{-1} \mathbb{E}(z_t \varepsilon_t) = (k_i^i, k_R^i, k_T^i)' v.$$  \hspace{1cm} (68)

Since $\Lambda = (\Lambda_1, \Lambda_2, \Lambda_3)'$ is a known $(3 \times 1)$ vector, we can identify the coefficients of interest, $(k_i^i, k_R^i, k_T^i)$ up to the sign of the scalar $v$. To see this, notice (68) implies

$$vk_i^i = \Lambda_1 \hspace{1cm} (69)$$
$$vk_R^i = \Lambda_2 \hspace{1cm} (70)$$
$$vk_T^i = \Lambda_3 \hspace{1cm} (71)$$

with

$$v^2 = \mathbb{E}(z_t u_t)' \Xi^{-1} \mathbb{E}(z_t u_t).$$  \hspace{1cm} (72)
Since the sign of \( v \) is unknown, we could look for restrictions that do not involve \( v \), and in this case these conditions only provide two additional restrictions on \( (k^R_i, k^T_i, k^R_T) \), i.e., combining (69) with (70), and (69) with (71), yields

\[
\frac{k^R_i}{k^T_i} = \frac{\Lambda_2}{\Lambda_1} \quad (73)
\]

\[
\frac{k^T_i}{k^T_T} = \frac{\Lambda_3}{\Lambda_1} \quad (74)
\]

Thus \( k^R_i \) and \( k^T_T \) are identified. From (69), \( k^T_i \) is also identified but up to the sign of \( v \).

Notice that if we run a two-stage least squares (2SLS) regression of \( u^R_t \) on \( u^T_t \) using \( z_t \) as instrument for \( u^T_t \), then the estimate of the slope coefficient on this regression is \( \Lambda_2/\Lambda_1 \).

Similarly, \( \Lambda_3/\Lambda_1 \) corresponds to the instrumental variable estimate of the slope coefficient of a regression of \( u^T_t \) on \( u^T_t \) using \( z_t \) as an instrument for \( u^T_t \).

In our application, as an instrument for the structural monetary policy shock, \( \varepsilon^T_t \), we use the (daily imputed) change in the 30-day federal funds futures from the level it has 10 minutes before the FOMC announcement and the level it has 20 minutes after the FOMC announcement.\(^{37}\) That is, we restrict our sample to \( t \in S_1 \) and set \( \{z_t\} = \{i_{t,m^*_t+20} - i_{t,m^*_t-10}\} \), where \( i_{t,m} \) denotes the (daily imputed) 30-day federal funds futures rate on minute \( m \) of day \( t \), and for any \( t \in S_1 \), \( m^*_t \) denotes the time of day (measured in minutes) when the FOMC announcement was made.\(^{38}\) All this leads to the following procedure, used by Mertens and Ravn (2013), Stock and Watson (2012), and Gertler and Karadi (2015), to identify the coefficients needed to estimate the empirical impulse responses to a monetary policy shock:

**Step 1:** Estimate the reduced-form VAR by least squares over the whole sample, \( S_0 \cup S_1 \), to obtain the coefficients \( \{B_j\}_{j=1}^J \) and the residuals \( \{u_t\} \).

\(^{37}\)By “daily imputed” we mean that in order to interpret the change in the fed funds futures rate as the surprise component of the change in the daily policy rate, it is adjusted for the fact that the federal funds futures contracts settle on the effective federal funds rate averaged over the month covered by the contract. See Appendix B.1.4 for details.

\(^{38}\)We use the data set constructed by Gorodnichenko and Weber (2016) with tick-by-tick data of the federal futures trades on the CME Globex electronic trading platform (as opposed to the open-outcry market). The variable we call \( z_t \) is the same variable that Gorodnichenko and Weber denote with \( v_t \). Their data are available at http://faculty.chicagobooth.edu/michael.weber/research/data/replication_dataset_gw.xlsx. We have also performed the estimations using a different instrument for the high-frequency external identification scheme, namely the 3-Month Eurodollar rate (on the nearest futures contract to expire after the FOMC announcement) from the level it has 10 minutes before the FOMC announcement and the level it has 20 minutes after the FOMC announcement. That is, we restrict our sample to \( t \in S_1 \) and set \( \{z_t\} = \{i^d_t,m^*_t+20 - i^d_t,m^*_t-10\} \), where \( i^d_t,m \) denotes the 3-Month Eurodollar futures rate on minute \( m \) of day \( t \), and for any \( t \in S_1 \), \( m^*_t \) denotes the time of day (measured in minutes) when the FOMC announcement was made. The results were essentially the same.
**Step 2:** Run the regression $u_i^t = \kappa_0 + \kappa_i z_t + \eta_t$ on sample $S_1$ to obtain the OLS estimates of $\kappa_0$ and $\kappa_i$, namely $\hat{\kappa}_0$ and $\hat{\kappa}_i$, and construct the fitted values $\hat{u}_i^t = \hat{\kappa}_0 + \hat{\kappa}_i z_t$.

**Step 3:** Run the regressions $u_{Rt}^t = \kappa_0 + \kappa_{R} \hat{u}_i^t + \eta_t$ and $u_{Tt}^t = \kappa_0 + \kappa_{T} \hat{u}_i^t + \eta_t$ on sample $S_1$ to obtain the OLS estimates of $\kappa_{R}$ and $\kappa_{T}$, namely $\hat{\kappa}_{R}$ and $\hat{\kappa}_{T}$. Since $\hat{\kappa}_{R} = \Lambda_2/\Lambda_1$ and $\hat{\kappa}_{T} = \Lambda_3/\Lambda_1$, (73) and (74) imply $\hat{\kappa}_{R} = k_{iR}/k_i$ and $\hat{\kappa}_{T} = k_{iT}/k_i$.

For the purpose of getting impulse responses with respect to the shock $\varepsilon_t^i$, notice that the scale and sign of $k_i$ are irrelevant, as they can be set by normalizing the shock $\varepsilon_t^i$ to have any desired impact on a given variable. For example, in our impulse responses we normalize the shock $\varepsilon_t^i$ so that it induces a 1 pp increase in the level of the policy rate $i_t$ on impact. To see this, consider (67) with $\varepsilon_{Rt}^i = \varepsilon_{Tt}^i = 0$. Then the shock that induces an $x$ pp increase in the level of the policy rate on impact (e.g., at $t = 0$), is $\varepsilon_t^i = (x/100)/k_i = (x/100)/(\Lambda_1/v)$.

**B.1.2 Confidence intervals for impulse responses**

The 95% confidence intervals for the impulse response coefficients estimated from the data are computed using a recursive wild bootstrap using 10,000 replications, as in Gonçalves and Kilian (2004) and Mertens and Ravn (2013). The procedure is as follows. Given the estimates of the reduced form VAR, $\hat{B}$, and the residual, $\{\hat{u}_t\}$, we generate bootstrap draws, $\{Y_t^b\}$, recursively, by $Y_t^b = \hat{B}Y_{t-1}^b + e_t^b \hat{u}_t$, where $e_t^b$ is the realization of a scalar random variable taking values of $-1$ or $1$, each with probability $1/2$. Our identification procedure also requires us to generate bootstrap draws for the proxy variable, $\{\Delta i_t^b\}$, so following Mertens and Ravn (2013), we generate random draws for the proxy variable via $\Delta i_t^b = e_t^b \Delta i_t$. We then use the bootstrap samples $\{Y_t^b\}$ and $\{\Delta i_t^b\}$ to reestimate the VAR coefficients and compute the associated impulse responses (applying the covariance restrictions implied by the bootstrapped instrument $\Delta i_t^b$). This gives one bootstrap estimate of the impulse response coefficients. The confidence intervals are the percentile intervals of the distribution of 10,000 bootstrap estimates for the impulse response coefficients.

**B.1.3 Lag length**

The Akaike information criterion (AIC) suggests a VAR specification with 10 lags, while Schwarz’s Bayesian information criterion (SBIC) and the Hannan and Quinn information crite-

\[^{39}\text{Alternatively, (69) and (72) can be combined to get } k_i' = \Lambda_1/v, \text{ which is then identified up to the sign of } v.\]
rion (HQIC) suggest a specification with 5 lags. In order to choose between these alternatives, we check which specification delivers a better estimate of the true impulse responses generated by the quantitative theory presented in Section 7. Specifically, the baseline parameters and the dividend process are calibrated as in Section 7.2. For the policy rate we adopt the AR(1) process estimated from the data reported in Section 7.2. We then proceed as follows:

1. Compute the equilibrium functions characterized by (25)-(28) for the calibrated model.

2. Simulate 1,000 samples of the dividend and the nominal rate, each sample of length equal to our data sample (2,014 days, which is the number of trading days between January 1, 1994 and December 31, 2001).

3. Compute the equilibrium of the model 1,000 times (one for each realization of the simulated dividend and interest rate paths) to produce 1,000 synthetic data samples for the nominal rate, the average stock return (of the equally weighted index), and turnover (of the equally weighted index), each consisting of 2,014 days.\(^{40}\)

4. For each synthetic data set, estimate our baseline VAR specification with 10 lags and an alternative specification with 5 lags. For each specification, calculate the impulse responses to a 1pp increase in the policy rate using the identification procedure described in Section B.1.1.

5. Calculate the average impulse responses over the 1,000 synthetic samples and calculate the 95% confidence bands using the distribution of estimates over the 1,000 synthetic samples. Do this for the specification with 10 lags and for the one with 5 lags.

6. Use the equilibrium conditions of the model to compute the true theoretical impulse responses to a 1pp increase in the policy rate (performing a linear interpolation if necessary).

Figure 7 reports the (average) impulse responses and the 95% confidence intervals corresponding to the VAR specifications with 5 and 10 lags, along with the true theoretical impulse responses implied by the equilibrium conditions. The impulse responses from the VAR specification with 10 lags and those from the VAR specification with 5 lags approximate the true theoretical responses about as well.

\(^{40}\)Measurement noise is added to the equilibrium path of the turnover rate as explained in footnote 33.
B.1.4 Changes in fed funds future rate and unexpected changes in the policy rate

Fix a month, \( s \), and let the intervals \( \{[t, t+1]\}_{t=0}^{T} \) denote the \( T \) days of the month. Let \( \{f_{s,t}^{0}\}_{t=1}^{T} \) denote the market prices of the fed funds futures contract at the end of day \( t \) of month \( s \). The superscript “0” indicates that \( s \) is the current month.\(^{41}\) Let \( \{r_{t}\}_{t=1}^{T} \) be the (average) daily fed funds rate calculated at the end of day \( t \). Finally, for \( j = 1, \ldots, T - t \), let \( E_{t}r_{t+j} \) denote the expectation conditional on the information available at the end of day \( t \). Then, since fed funds future contracts settle on the average daily rate of the month, we have

\[
f_{s,t}^{0} = \frac{1}{T} \left[ \sum_{i=1}^{t} r_{i} + \sum_{i=t+1}^{T} E_{t}r_{i} \right], \quad \text{for } t = 1, \ldots, T.
\]

Hence

\[
f_{s,t}^{0} - f_{s,t-1}^{0} = \frac{1}{T} \left( r_{t} - E_{t-1}r_{t} \right) + \frac{1}{T} \sum_{i=t+1}^{T} E_{t}r_{i} - \frac{1}{T} \sum_{i=t+1}^{T} E_{t-1}r_{i}, \quad \text{for } t = 1, \ldots, T,
\]

where \( f_{s,0}^{0} \equiv f_{s-1,T}^{1} \). Assume the fed funds rate changes at most once during the month and suppose that it is known that the announcement takes place at the beginning of day \( t \geq 1 \).\(^{42}\)

Then

\[
E_{t}r_{i} = r_{t} \quad \text{for } j = t, \ldots, T
\]

\[
E_{t-1}r_{i} = E_{t-1}r_{t} \quad \text{for } i = t + 1, \ldots, T.
\]

Thus the change in the forward rate at the time of the announcement is

\[
f_{s,t}^{0} - f_{s,t-1}^{0} = \frac{T + 1 - t}{T} \left( r_{t} - E_{t-1}r_{t} \right), \quad \text{for } t = 1, \ldots, T, \quad (75)
\]

where \( r_{t} - E_{t-1}r_{t} \) is the surprise change in the fed funds rate on day \( t \) (the day of the policy announcement). From (75) we if we know the daily changes in the forward rate at the time of the announcement, \( \{f_{s,t}^{0} - f_{s,t-1}^{0}\}_{t=1}^{T} \), we can recover the unexpected change in the fed funds rate on the day of the FOMC announcement, \( t \), as follows:

\[
r_{t+1} - E_{t}r_{t+1} = \frac{T}{T - t} \left( f_{s,t+1}^{0} - f_{s,t}^{0} \right) \quad \text{for } t = 0, \ldots, T - 1, \quad (76)
\]

\(^{41}\)Contracts can range from 1 to 5 months. For example, \( f_{s,t}^{5} \) would be the price of the 5-month forward on day \( t \) of month \( s \).

\(^{42}\)If \( r_{t} \) were the actual target fed funds rate, then the assumption that it changes at most once in the month would be exactly true for most of our sample, see. e.g., footnote 16 in Gorodnichenko and Weber (2016). In general this has to be regarded as an approximation since on any given day the effective fed funds rate, \( r_{t} \), can and does deviate somewhat from the announced fed funds rate target rate (see Afonso and Lagos, 2014).
This condition is the same as condition (7) in Kuttner (2001), which is the convention used by the event-study literature to map the change in the 30-day fed funds future rate on the day of the FOMC policy announcement into the surprise change in the daily policy rate on the day of the announcement. In terms of the notation for our instrument introduced in Section B.1.1, we set \( z_t = \frac{m}{T-1} \left( f_{s,t+1}^{0} - f_{s,t}^{0} \right) \equiv i_{t,m_{t}^{+}+20} - i_{t,m_{t}^{+}+10} \), where \( f_{s,t+1}^{0} - f_{s,t}^{0} \) is measured (using high-frequency data) as the change in the 30-day fed funds future rate over a 30-minute window around the FOMC announcement that takes place on day \( t \).

### B.2 Equilibrium conditions for the model with \( M \) states and \( N \) assets

Let the state of this economy be \( \mathbf{x}_t = \left( (A^{ms}_{t,s})_{s \in \mathbb{N}}, A^{m}_t, y_t, \mu_t \right) \in \mathbb{R}^{N+3}_+ \), where \( A^{ms}_{t,s} \) denotes the amount of money that investors have available to trade asset \( s \) at the beginning of period \( t \).

The laws of motion for the state variables \( A^{m}_t, y_t, \) and \( \mu_t \) are exogenous (as described above) while \( A^{ms}_{t+1} = \Psi^{ms} (\mathbf{x}_t) \), where the function \( \Psi^{ms} \) is determined in equilibrium. Asset prices in the recursive equilibrium are time-invariant functions of the state, i.e., \( \phi^{s}_t = \phi^{s} (\mathbf{x}_t) \), \( \bar{\phi}^{s}_t = \bar{\phi}^{s} (\mathbf{x}_t) \), \( \bar{\phi}^{m}_t = \phi^{m} (\mathbf{x}_t) \), \( p^{s}_t = p^{s} (\mathbf{x}_t) \), and \( \bar{\varepsilon}^{s*} = \varepsilon^{s*} (\mathbf{x}_t) \). Lemma 1 still characterizes the equilibrium post-trade portfolios of dealers and investors in the OTC market. The investor’s value functions are

\[
W^I ((a^{ms}_{t,s}, a^{s}_t)_{s \in \mathbb{N}}, -k_t; \mathbf{x}_t) = \sum_{s \in \mathbb{N}} [\phi^{m} (\mathbf{x}_t) a^{ms}_{t,s} + \phi^{s} (\mathbf{x}_t) a^{s}_{t,s}] - k_t + \bar{W}^I (\mathbf{x}_t)
\]

\[
V^I ((a^{ms}_{t,s}, a^{s}_t)_{s \in \mathbb{N}}, \varepsilon; \mathbf{x}_t) = \sum_{s \in \mathbb{N}} \{ \phi^{m} (\mathbf{x}_t) a^{ms}_{t,s} + [\varepsilon y_t + \phi^{s} (\mathbf{x}_t)] a^{s}_{t,s} \} + \bar{W}^I (\mathbf{x}_t)
\]

\[
+ \sum_{s \in \mathbb{N}} \left\{ \alpha^s \theta [\varepsilon - \varepsilon^{s*} (\mathbf{x}_t)] y_t [\varepsilon^{s*} (\mathbf{x}_t) < \bar{\varepsilon}] \frac{1}{p^{s} (\mathbf{x}_t)} a^{ms}_{t,s} + \alpha^s \theta [\varepsilon^{s*} (\mathbf{x}_t) - \varepsilon] y_t [\varepsilon < \varepsilon^{s*} (\mathbf{x}_t)] a^{s}_{t,s} \right\}
\]

where

\[
\bar{W}^I (\mathbf{x}_t) \equiv T (\mathbf{x}_t) + \max_{(\tilde{a}^{ms}_{t+1}, \tilde{a}^{s}_{t+1})_{s \in \mathbb{N}} \in \mathbb{R}^{2N}_+} \left\{ - \sum_{s \in \mathbb{N}} [\phi^{m} (\mathbf{x}_t) \tilde{a}^{ms}_{t+1,s} + \phi^{s} (\mathbf{x}_t) \tilde{a}^{s}_{t+1,s}] \right\}
\]

\[
+ \beta \mathbb{E} \left[ \int V^I \left( (\tilde{a}^{ms}_{t+1}, \tilde{a}^{s}_{t+1})_{s \in \mathbb{N}}, \varepsilon; \mathbf{x}_{t+1} \right) dG(\varepsilon) \bigg\vert \mathbf{x}_t \right]\}
\]

with \( T (\mathbf{x}_t) \equiv (\mu_t - 1) \phi^{m} (\mathbf{x}_t) A^{m}_t \) and \( a^{s}_{t+1,t+1} \equiv \delta a^{s}_{t+1} (1 - \delta) A^s \).

---

63 As it will become clear, the state can be reduced to \( \mathbf{x}_t = (A^{m}_t, y_t, \mu_t) \) in the class of equilibria we consider.
Lemma 5 Let $(\tilde a^m_{t+1}, \tilde a^s_{t+1})_{s \in \mathbb{N}}$ denote the portfolios chosen by an investor in the second sub-period of period $t$ of a recursive equilibrium. These portfolios must satisfy the following first-order necessary and sufficient conditions:

\[
\begin{align*}
&\phi^m(x_t) \geq \beta \mathbb{E} \left[ \phi^m(x_{t+1}) + \alpha s \theta \int_{\epsilon_s^s(x_{t+1})}^{\epsilon_H(x_{t+1})} \left[ \epsilon - \epsilon_s^s(x_{t+1}) \right] y_{t+1} dG(\epsilon) \frac{1}{p^s(x_{t+1})} \right] x_t \tag{77} \\
&\phi^s(x_t) \geq \beta \delta \mathbb{E} \left[ \tilde \epsilon y_{t+1} + \phi^s(x_{t+1}) + \alpha s \theta \int_{\epsilon_L}^{\epsilon_s^s(x_{t+1})} \left[ \epsilon_s^s(x_{t+1}) - \tilde \epsilon \right] y_{t+1} dG(\epsilon) \right] x_t \tag{78}
\end{align*}
\]

where (77) holds with “=” if $\tilde a^m_{t+1} > 0$ and (78) holds with “=” if $\tilde a^s_{t+1} > 0$.

Proof. The proof is similar to the proof of Lemma 2, so it is omitted. ■

Definition 2 A recursive equilibrium for the economy in which only investors can hold equity overnight is a collection of functions

\[ \{ \phi^m(\cdot), \phi^s(\cdot), p^s(\cdot), \tilde \epsilon_s^s(\cdot), \Psi^{ms}(\cdot) \}_{s \in \mathbb{N}} \]

that satisfy

\[
\begin{align*}
&\phi^m(x_t) \geq \beta \mathbb{E} \left[ \phi^m(x_{t+1}) + \alpha s \theta \int_{\epsilon_s^s(x_{t+1})}^{\epsilon_H(x_{t+1})} \left[ \epsilon - \epsilon_s^s(x_{t+1}) \right] y_{t+1} dG(\epsilon) \frac{1}{p^s(x_{t+1})} \right] x_t \\
&\phi^s(x_t) \geq \beta \delta \mathbb{E} \left[ \tilde \epsilon y_{t+1} + \phi^s(x_{t+1}) + \alpha s \theta \int_{\epsilon_L}^{\epsilon_s^s(x_{t+1})} \left[ \epsilon_s^s(x_{t+1}) - \tilde \epsilon \right] y_{t+1} dG(\epsilon) \right] x_t \\
p^s(x_t) = \frac{1 - G(\epsilon_s^s(x_t))}{G(\epsilon_s^s(x_t))} \frac{A^{ms}_{t+1}}{A^s} \\
\tilde \epsilon_s^s(x_t) = \frac{p^s(x_t) \phi^m(x_t) - \phi^s(x_t)}{y_t} \\
A^{ms}_{t+1} = \Psi^{ms}(x_t) \\
\sum_{s \in \mathbb{N}} A^{ms}_{t+1} = A^m_{t+1}
\end{align*}
\]

where the first condition holds with equality if $A^{ms}_{t+1} > 0$.

We conjecture the recursive equilibrium has the property that real prices are linear functions
of the aggregate dividend, i.e., suppose \( x_t = (A^m_t, y_t, \mu_t) \). Then

\[
\phi^s(x_t) = \phi^s_i y_t
\]  
(79)

\[
\bar{\phi}^s(x_t) \equiv p^s(x_t) \phi^m(x_t) = \bar{\phi}^s_i y_t
\]  
(80)

\[
\phi^m(x_t) A^m_t = Z_i y_t
\]  
(81)

\[
\phi^m(x_t) A^{ms}_t = Z_i^s y_t
\]  
(82)

\[
\varepsilon^{**}(x_t) \equiv \frac{\bar{\phi}^s(x_t) - \phi^s(x_t)}{y_t} = \bar{\phi}^s_i - \phi^s_i \equiv \varepsilon^{**}_i
\]  
(83)

and the equilibrium conditions reduce to (25)-(28). Once (25)-(28) have been solved for \( \{\varepsilon^{**}_i, \phi^s_i, Z^s_i, Z_i\}_{i \in M, s \in N} \), for any given \( x_t = (A^m_t, y_t, \mu_t) \), \( \phi^s(x_t) \) is obtained from (79), \( \bar{\phi}^s(x_t) \) from (80) (with \( \bar{\phi}^s_i = \varepsilon^{**}_i + \phi^s_i \)), \( \phi^m(x_t) \) from (81), and \( A^{ms}_t \) from (82).
References


[54] Li, Ying-Syuan, and Yiting Li. “Liquidity, Asset Prices, and Credit Constraints.” National Taiwan University, mimeo, 2012.


Figure 1: Effects of monetary policy and OTC frictions on asset prices.
Table 1: Empirical response of stock returns and turnover to monetary policy. All estimates are significant at 1% level.

<table>
<thead>
<tr>
<th></th>
<th>E-study</th>
<th>H-based</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Std dev</td>
</tr>
<tr>
<td>Return</td>
<td>-3.77</td>
<td>1.02</td>
</tr>
<tr>
<td>Turnover</td>
<td>-.0025</td>
<td>.0007</td>
</tr>
<tr>
<td>Portfolio</td>
<td>Turnover</td>
<td>Return</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Estimate</td>
</tr>
<tr>
<td>1</td>
<td>.11</td>
<td>-2.03***</td>
</tr>
<tr>
<td>2</td>
<td>.19</td>
<td>-1.83**</td>
</tr>
<tr>
<td>3</td>
<td>.25</td>
<td>-1.57*</td>
</tr>
<tr>
<td>4</td>
<td>.31</td>
<td>-1.05</td>
</tr>
<tr>
<td>5</td>
<td>.37</td>
<td>-2.54**</td>
</tr>
<tr>
<td>6</td>
<td>.42</td>
<td>-2.67***</td>
</tr>
<tr>
<td>7</td>
<td>.47</td>
<td>-3.33***</td>
</tr>
<tr>
<td>8</td>
<td>.53</td>
<td>-2.55**</td>
</tr>
<tr>
<td>9</td>
<td>.58</td>
<td>-2.65**</td>
</tr>
<tr>
<td>10</td>
<td>.65</td>
<td>-4.33***</td>
</tr>
<tr>
<td>11</td>
<td>.71</td>
<td>-3.88***</td>
</tr>
<tr>
<td>12</td>
<td>.78</td>
<td>-3.76***</td>
</tr>
<tr>
<td>13</td>
<td>.86</td>
<td>-3.98***</td>
</tr>
<tr>
<td>14</td>
<td>.95</td>
<td>-4.73***</td>
</tr>
<tr>
<td>15</td>
<td>1.06</td>
<td>-4.69***</td>
</tr>
<tr>
<td>16</td>
<td>1.19</td>
<td>-5.37***</td>
</tr>
<tr>
<td>17</td>
<td>1.36</td>
<td>-6.02***</td>
</tr>
<tr>
<td>18</td>
<td>1.61</td>
<td>-5.21***</td>
</tr>
<tr>
<td>19</td>
<td>2.02</td>
<td>-5.93***</td>
</tr>
<tr>
<td>20</td>
<td>3.11</td>
<td>-6.27***</td>
</tr>
</tbody>
</table>

Table 2: Empirical responses of stock returns and turnover to monetary policy across NYSE liquidity portfolios. *** denotes significance at 1% level, ** significance at 5% level, * significance at 10% level.
<table>
<thead>
<tr>
<th>Variable</th>
<th>(I)</th>
<th>(II)</th>
<th>(III)</th>
<th>(IV)</th>
<th>(V)</th>
<th>(VI)</th>
<th>(VII)</th>
<th>(VIII)</th>
<th>(IX)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(.086)</td>
<td>(.090)</td>
<td>(.091)</td>
<td>(.097)</td>
<td>(.098)</td>
<td>(.099)</td>
<td>(.100)</td>
<td>(.110)</td>
<td>(.110)</td>
</tr>
<tr>
<td>$T^*_t$</td>
<td>25.93</td>
<td>25.36</td>
<td>17.54</td>
<td>22.37</td>
<td>13.93</td>
<td>45.29</td>
<td>42.58</td>
<td>39.09</td>
<td>33.13</td>
</tr>
<tr>
<td></td>
<td>(2.26)</td>
<td>(2.26)</td>
<td>(3.08)</td>
<td>(2.29)</td>
<td>(3.16)</td>
<td>(5.71)</td>
<td>(7.55)</td>
<td>(5.72)</td>
<td>(7.71)</td>
</tr>
<tr>
<td>$T^*_t \times \Delta i_t$</td>
<td>-109.43</td>
<td>-121.14</td>
<td>-100.43</td>
<td>-111.09</td>
<td>-403.98</td>
<td>-415.17</td>
<td>-398.96</td>
<td>-410.15</td>
<td></td>
</tr>
<tr>
<td>$D_s$</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>$D_t$</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$(\Delta i_t)^2$</td>
<td>.947</td>
<td>.947</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.041)</td>
<td>(.042)</td>
<td>(.042)</td>
<td>(.043)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$(T^*_t)^2$</td>
<td>-1696.88</td>
<td>-1921.29</td>
<td>-1378.21</td>
<td>-1418.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(392.48)</td>
<td>(465.31)</td>
<td>(389.33)</td>
<td>(466.21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>.0084</td>
<td>.0086</td>
<td>.0085</td>
<td>.0314</td>
<td>.0316</td>
<td>.0132</td>
<td>.0132</td>
<td>.0363</td>
<td>.0364</td>
</tr>
</tbody>
</table>

Table 3: Effects of monetary policy on stock returns of individual stocks. Each column reports the coefficients from a separate pooled OLS regression based on (3). Number of observations: 117,487. Standard errors in parenthesis. All estimates are significant at 1% level.
Figure 2: Empirical impulse responses to a 1 percentage point increase in the policy rate. Solid lines are point estimates. Broken lines are 95 percent confidence intervals.
Figure 3: Estimates of announcement-day response of stock return to policy rate.
Figure 4: Cross-sectional announcement-day responses of stock returns to policy rate.
Response of Turnover Rate to Policy Rate: Model and Data

Figure 5: Cross-sectional announcement-day normalized responses of turnover rates to policy rate.
Figure 6: Impulse responses to a 1 percentage point increase in the policy rate. Solid lines are point estimates. Broken lines are 95 percent confidence intervals.
Figure 7: Model-based impulse responses to a 1 percentage point increase in the policy rate. Solid lines are point estimates. Broken lines are 95 percent confidence intervals.