

Turnover Liquidity and the Transmission of Monetary Policy

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Abstract

In this paper we document a novel liquidity-based transmission mechanism through which monetary policy influences asset markets, we develop a model of this mechanism, and use a quantitative version to assess the ability of the theory to match the evidence.

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1 Introduction

In most modern economies central banks implement monetary policy indirectly by intervening in financial markets (e.g., in the United States, the Fed Funds market and the market for Treasuries), expecting the effects those interventions have on asset prices and returns will themselves be transmitted to the rest of the macroeconomy to help achieve the ultimate policy objectives. It is for this reason that understanding the transmission mechanism of monetary policy to asset prices is crucial 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 do three things. First, we provide empirical evidence of a novel channel through which monetary policy influences asset markets—what we call the *turnover liquidity transmission mechanism of monetary policy*. Tight money increases the opportunity cost of holding the nominal assets that are routinely used to settle financial transactions (e.g. bank reserves, real money balances) making these payment instruments more scarce. In turn, this scarcity reduces asset resalability and turnover and this increased illiquidity is reflected in a reduction of the equity price. Second, we develop a monetary theory of exchange in financial markets and use it to show 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), generate speculative bubbles, and—consistent with the evidence—can offer a liquidity based explanation for the negative correlation between real stock returns and unexpected increases in the nominal interest rate used to implement monetary policy. Third, we calibrate a generalized version of the basic model and conduct a number of quantitative theoretical exercises geared to assess the ability of the theory to match the evidence.

2 The model

Time is represented by a sequence of periods indexed by $t = 0, 1, \dots$. 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 $\mathcal{I} = [0, 1]$. There is also a continuum of infinitely lived agents called *dealers*, each identified with a point in the set $\mathcal{D} = [0, 1]$. 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 γ_{t+1} is a nonnegative random variable with cumulative distribution function Γ , i.e., $\Pr(\gamma_{t+1} \leq \gamma) = \Gamma(\gamma)$, 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_t^m . The initial stock of money, $A_0^m \in \mathbb{R}_{++}$, is given and $A_{t+1}^m = \mu A_t^m$, 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 α .) 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 in the second subperiod of period t , and h_{dt} is the utility cost from exerting h_{dt} units of effort to produce this good. The expectation operator $\mathbb{E}_0^d$ 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

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (\varepsilon_{it} y_{it} + c_{it} - h_{it})$$

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 ε_{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 ε_{it} at the beginning of period t , before the OTC trading round. The expectation

¹As 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.

²This 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).

operator $\mathbb{E}_0$ 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 α 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} 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} denote a measure on $\mathcal{F}([\varepsilon_L, \varepsilon_H])$, the Borel σ -field defined on $[\varepsilon_L, \varepsilon_H]$. 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,

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

to maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\alpha \int_{\varepsilon_L}^{\varepsilon_H} \varepsilon y_t a'_{It} (d\varepsilon) + (1 - \alpha) \int_{\varepsilon_L}^{\varepsilon_H} \varepsilon y_t a_{It} dG(\varepsilon) + c_{Dt} + c_{It} - h_{Dt} - h_{It} \right]$$

(the expectation operator $\mathbb{E}_0$ is with respect to the probability measure induced by the dividend process) subject to

$$\tilde{a}_{Dt} + \tilde{a}_{It} \leq A^s \tag{1}$$

$$a'_{Dt} + \alpha \int_{\varepsilon_L}^{\varepsilon_H} a'_{It} (d\varepsilon) \leq a_{Dt} + \alpha a_{It} \tag{2}$$

$$c_{Dt} + c_{It} \leq h_{Dt} + h_{It} \tag{3}$$

$$a_{Dt} = \delta \tilde{a}_{Dt} \tag{4}$$

$$a_{It} = \delta \tilde{a}_{It} + (1 - \delta) A^s. \tag{5}$$

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) $a'_{It}(E) = \mathbb{I}_{\{\varepsilon_H \in E\}} [\delta + \alpha(1 - \delta)] A^s / \alpha$, where $\mathbb{I}_{\{\varepsilon_H \in E\}}$ 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 $\mathbf{a}_{dt}$ and an investor with portfolio $\mathbf{a}_{it}$ and valuation type ε . Let $\bar{\mathbf{a}}_t = (\bar{a}_t^m, \bar{a}_t^s)$ 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.³ We take $(\bar{\mathbf{a}}_t, k_t)$ to be determined by the Nash bargaining solution where the investor has bargaining power $\theta \in [0, 1]$. Let $\hat{W}_t^D(\mathbf{a}_{dt}, k_t)$ 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 $W_t^I(\mathbf{a}_{it}, -k_t)$ 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 $\mathbf{a}_{it}$ and has to pay a dealer fee k_t . For each t , define a pair of functions $\bar{a}_t^k : \mathbb{R}_+^2 \times [\varepsilon_L, \varepsilon_H] \rightarrow \mathbb{R}_+$ for $k = m, s$ and a function $k_t : \mathbb{R}_+^2 \times [\varepsilon_L, \varepsilon_H] \rightarrow \mathbb{R}$, and let $\bar{\mathbf{a}}_t(\mathbf{a}_{it}, \varepsilon) = (\bar{a}_t^m(\mathbf{a}_{it}, \varepsilon), \bar{a}_t^s(\mathbf{a}_{it}, \varepsilon))$ for each $(\mathbf{a}_{it}, \varepsilon) \in \mathbb{R}_+^2 \times [\varepsilon_L, \varepsilon_H]$. We use $[\bar{\mathbf{a}}_t(\mathbf{a}_{it}, \varepsilon), k_t(\mathbf{a}_{it}, \varepsilon)]$ to represent the bargaining outcome for a bilateral meeting at time t between an investor with portfolio $\mathbf{a}_{it}$ and valuation type ε , and a dealer with portfolio $\mathbf{a}_{dt}$. That is, $[\bar{\mathbf{a}}_t(\mathbf{a}_{it}, \varepsilon), k_t(\mathbf{a}_{it}, \varepsilon)]$ is the solution to

$$\max_{(\bar{\mathbf{a}}_t, k_t) \in \mathbb{R}_+^2 \times \mathbb{R}} [\varepsilon y_t \bar{a}_t^s + W_t^I(\bar{\mathbf{a}}_t, -k_t) - \varepsilon y_t a_{it}^s - W_t^I(\mathbf{a}_{it}, 0)]^\theta [\hat{W}_t^D(\mathbf{a}_{dt}, k_t) - \hat{W}_t^D(\mathbf{a}_{dt}, 0)]^{1-\theta} \quad (6)$$

³In 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.

$$\begin{aligned}
& \text{s.t. } \bar{a}_t^m + p_t \bar{a}_t^s \leq a_{it}^m + p_t a_{it}^s \\
& \hat{W}_t^D(\mathbf{a}_{dt}, 0) \leq \hat{W}_t^D(\mathbf{a}_{dt}, k_t) \\
& \varepsilon y_t a_{it}^s + W_t^I(\mathbf{a}_{it}, 0) \leq \varepsilon y_t \bar{a}_t^s + W_t^I(\bar{\mathbf{a}}_t, -k_t)
\end{aligned}$$

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

Let $W_t^D(\mathbf{a}_t, k_t)$ 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

$$\begin{aligned}
\hat{W}_t^D(\mathbf{a}_t, k_t) &= \max_{\hat{\mathbf{a}}_t \in \mathbb{R}_+^2} W_t^D(\hat{\mathbf{a}}_t, k_t) \\
&\text{s.t. } \hat{a}_t^m + p_t \hat{a}_t^s \leq a_t^m + p_t a_t^s
\end{aligned} \tag{7}$$

where $\hat{\mathbf{a}}_t \equiv (\hat{a}_t^m, \hat{a}_t^s)$. For each t , define a pair of functions $\hat{a}_t^k : \mathbb{R}_+^2 \rightarrow \mathbb{R}_+$ 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 $V_t^D(\mathbf{a}_t)$ 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 ϕ_t^m is the real price of money and ϕ_t^s the real *ex dividend* price of equity in the second subperiod of period t (both expressed in terms of the second-subperiod consumption good). Then,

$$\begin{aligned}
W_t^D(\mathbf{a}_t, k_t) &= \max_{(c_t, h_t, \tilde{\mathbf{a}}_{t+1}) \in \mathbb{R}_+^4} [c_t - h_t + \beta \mathbb{E}_t V_{t+1}^D(\mathbf{a}_{t+1})] \\
&\text{s.t. } c_t + \phi_t \tilde{\mathbf{a}}_{t+1} \leq h_t + k_t + \phi_t \mathbf{a}_t
\end{aligned} \tag{8}$$

where $\tilde{\mathbf{a}}_{t+1} \equiv (\tilde{a}_{t+1}^m, \tilde{a}_{t+1}^s)$, $\mathbf{a}_{t+1} = (\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s)$, $\mathbb{E}_t$ is the conditional expectation over the next-period realization of the dividend, and $\phi_t \mathbf{a}_t$ denotes the dot product of ϕ_t and $\mathbf{a}_t$. Similarly, let $V_t^I(\mathbf{a}_t, \varepsilon)$ denote the maximum expected discounted payoff of an investor with valuation type ε and portfolio $\mathbf{a}_t \equiv (a_t^m, a_t^s)$ at the beginning of the OTC round of period t . Then,

$$\begin{aligned}
W_t^I(\mathbf{a}_t, -k_t) &= \max_{(c_t, h_t, \tilde{\mathbf{a}}_{t+1}) \in \mathbb{R}_+^4} \left[c_t - h_t + \beta \mathbb{E}_t \int V_{t+1}^I(\mathbf{a}_{t+1}, \varepsilon') dG(\varepsilon') \right] \\
&\text{s.t. } c_t + \phi_t \tilde{\mathbf{a}}_{t+1} \leq h_t - k_t + \phi_t \mathbf{a}_t + T_t
\end{aligned} \tag{9}$$

where $\mathbf{a}_{t+1} = (\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s + (1 - \delta) A^s)$ and $T_t \in \mathbb{R}$ is the real value of the time- t lump-sum monetary transfer.

The value function of an investor who enters the OTC round of period t with portfolio $\mathbf{a}_t$ and valuation type ε is

$$V_t^I(\mathbf{a}_t, \varepsilon) = \alpha \{ \varepsilon y_t \bar{a}_t^s(\mathbf{a}_t, \varepsilon) + W_t^I[\bar{\mathbf{a}}_t(\mathbf{a}_t, \varepsilon), -k_t(\mathbf{a}_t, \varepsilon)] \} + (1 - \alpha) [\varepsilon y_t a_t^s + W_t^I(\mathbf{a}_t, 0)].$$

The value function of a dealer who enters the OTC round of period t with portfolio $\mathbf{a}_t$ is

$$V_t^D(\mathbf{a}_t) = \alpha \int \hat{W}_t^D[\mathbf{a}_t, k_t(\mathbf{a}_{it}, \varepsilon)] dH_{It}(\mathbf{a}_{it}, \varepsilon) + (1 - \alpha) \hat{W}_t^D(\mathbf{a}_t, 0)$$

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_{jt}^m and A_{jt}^s 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, $A_{jt}^m = \int a_t^m dF_{jt}(\mathbf{a}_t)$ and $A_{jt}^s = \int a_t^s dF_{jt}(\mathbf{a}_t)$, where F_{jt} is the cumulative distribution function over portfolios $\mathbf{a}_t = (a_t^m, a_t^s)$ held by agents of type j at the beginning of the OTC round of period t . Let $\tilde{A}_{jt+1}^m$ and $\tilde{A}_{jt+1}^s$ denote the total quantities of money and shares held by all agents of type j at the end of period t , i.e., $\tilde{A}_{Dt+1}^k = \int_{\mathcal{D}} \tilde{a}_{xt+1}^k dx$ and $\tilde{A}_{It+1}^k = \int_{\mathcal{I}} \tilde{a}_{it+1}^k di$ for $k \in \{s, m\}$, with $A_{Dt+1}^m = \tilde{A}_{Dt+1}^m$, $A_{Dt+1}^s = \delta \tilde{A}_{Dt+1}^s$, $A_{It+1}^m = \tilde{A}_{It+1}^m$, and $A_{It+1}^s = \delta \tilde{A}_{It+1}^s + (1 - \delta) A_{It}^s$. Let $\bar{A}_{Dt}^m$ and $\bar{A}_{Dt}^s$ denote the quantities of money and shares held after the OTC round of trade of period t by all the dealers, and let $\bar{A}_{It}^m$ and $\bar{A}_{It}^s$ 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 $k \in \{s, m\}$, $\bar{A}_{Dt}^k = \int \hat{a}_t^k(\mathbf{a}_t) dF_{Dt}(\mathbf{a}_t)$ and $\bar{A}_{It}^k = \alpha \int \tilde{a}_t^k(\mathbf{a}_t, \varepsilon) dH_{It}(\mathbf{a}_t, \varepsilon)$. 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, $\{\bar{\mathbf{a}}_t, k_t\}_{t=0}^\infty$, dealer portfolios, $\{\langle \hat{\mathbf{a}}_{dt}, \tilde{\mathbf{a}}_{dt+1}, \mathbf{a}_{dt+1} \rangle_{d \in \mathcal{D}}\}_{t=0}^\infty$, and investor portfolios, $\{\langle \tilde{\mathbf{a}}_{it+1}, \mathbf{a}_{it+1} \rangle_{i \in \mathcal{I}}\}_{t=0}^\infty$, such that for all t : (i) the bilateral terms of trade $\{\bar{\mathbf{a}}_t, k_t\}_{t=0}^\infty$ solve (6), (ii) taking prices and the bargaining protocol as given, the portfolios $\langle \hat{\mathbf{a}}_{dt}, \tilde{\mathbf{a}}_{dt+1}, \mathbf{a}_{dt+1} \rangle$ solve the individual dealer’s optimization problems (7) and (8), and the portfolios $\langle \tilde{\mathbf{a}}_{it+1}, \mathbf{a}_{it+1} \rangle$ 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., $\tilde{A}_{Dt+1}^s + \tilde{A}_{It+1}^s = A^s$ (the end-of-period- t Walrasian market for equity clears), $\tilde{A}_{Dt+1}^m + \tilde{A}_{It+1}^m = A_{t+1}^m$ (the end-of-period- t Walrasian market for money clears), and $\bar{A}_{Dt}^k + \bar{A}_{It}^k = A_{Dt}^k + \alpha A_{It}^k$ 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 $\varepsilon_t^* \equiv \frac{p_t \phi_t^m - \phi_t^s}{y_t}$ and

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

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 ε . The investor's post-trade portfolio, $[\bar{a}_t^m(\mathbf{a}_t, \varepsilon), \bar{a}_t^s(\mathbf{a}_t, \varepsilon)]$, is given by

$$\begin{aligned} \bar{a}_t^m(\mathbf{a}_t, \varepsilon) &= [1 - \chi(\varepsilon_t^*, \varepsilon)] (a_t^m + p_t a_t^s) \\ \bar{a}_t^s(\mathbf{a}_t, \varepsilon) &= \chi(\varepsilon_t^*, \varepsilon) (1/p_t) (a_t^m + p_t a_t^s) \end{aligned}$$

and the intermediation fee charged by the dealer is

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

A dealer who enters the OTC market with portfolio $\mathbf{a}_{dt}$, exits the OTC market with portfolio $[\hat{a}_t^m(\mathbf{a}_{dt}), \hat{a}_t^s(\mathbf{a}_{dt})] = [\bar{a}_t^m(\mathbf{a}_{dt}, 0), \bar{a}_t^s(\mathbf{a}_{dt}, 0)]$.

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, ε , is above or below a cutoff, ε_t^* . If $\varepsilon_t^* < \varepsilon$, the investor uses all his cash to buy equity, i.e., if his pre-trade portfolio is $\mathbf{a}_t$, then his post-trade portfolio is $(\bar{a}_t^m(\mathbf{a}_t, \varepsilon), \bar{a}_t^s(\mathbf{a}_t, \varepsilon)) = (0, a_t^s + a_t^m/p_t)$. Conversely, if $\varepsilon < \varepsilon_t^*$, then he sells all his equity holding for cash, i.e., his post-trade portfolio is $(\bar{a}_t^m(\mathbf{a}_t, \varepsilon), \bar{a}_t^s(\mathbf{a}_t, \varepsilon)) = (a_t^m + p_t a_t^s, 0)$. 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 $(1 - \theta) (\varepsilon - \varepsilon_t^*) \frac{1}{p_t} a_t^m y_t$. If $\varepsilon < \varepsilon_t^*$, the fee equals $(1 - \theta) (\varepsilon_t^* - \varepsilon) a_t^s y_t$. 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., $A_{Dt}^s = A_D^s$ and $A_{It}^s = A_I^s$ for all t , real asset prices are time-invariant linear functions of the aggregate dividend, i.e., $\phi_t^s = \phi^s y_t$, $p_t \phi_t^m \equiv \bar{\phi}_t^s = \bar{\phi}^s y_t$, $\phi_t^m A_{It}^m = Z y_t$, and $\phi_t^m A_{Dt}^m = Z_D y_t$. Hence, in a stationary equilibrium, $\varepsilon_t^* = \bar{\phi}^s - \phi^s \equiv \varepsilon^*$, $\phi_{t+1}^s / \phi_t^s = \bar{\phi}_{t+1}^s / \bar{\phi}_t^s = \gamma_{t+1}$, $\phi_t^m / \phi_{t+1}^m = \mu / \gamma_{t+1}$, 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

$$\hat{\mu} \equiv \bar{\beta} \left[1 + \frac{(1 - \alpha\theta)(1 - \bar{\beta}\delta)(\hat{\varepsilon} - \bar{\varepsilon})}{\hat{\varepsilon}} \right] \quad \text{and} \quad \bar{\mu} \equiv \bar{\beta} \left[1 + \frac{\alpha\theta(1 - \bar{\beta}\delta)(\bar{\varepsilon} - \varepsilon_L)}{\bar{\beta}\delta\bar{\varepsilon} + (1 - \bar{\beta}\delta)\varepsilon_L} \right] \quad (10)$$

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

$$\bar{\varepsilon} - \hat{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^{\hat{\varepsilon}} (\hat{\varepsilon} - \varepsilon) dG(\varepsilon) = 0. \quad (11)$$

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, $A_I^s = A^s - A_D^s = A^s$ (only investors hold equity shares), there is no trade in the OTC market, and the equity price in the Walrasian market is

$$\phi_t^s = \phi^s y_t, \text{ with } \phi^s = \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \bar{\varepsilon}. \quad (12)$$

(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 $A_{Dt}^m = A_t^m - A_{It}^m = 0$ and

$$A_D^s = A^s - A_I^s \begin{cases} = \delta A^s & \text{if } \bar{\beta} < \mu < \hat{\mu} \\ \in [0, \delta A^s] & \text{if } \mu = \hat{\mu} \\ = 0 & \text{if } \hat{\mu} < \mu < \bar{\mu} \end{cases}$$

and asset prices are

$$\phi_t^s = \phi^s y_t, \text{ with } \phi^s = \begin{cases} \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \varepsilon^* & \text{if } \bar{\beta} < \mu \leq \hat{\mu} \\ \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \left[\bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right] & \text{if } \hat{\mu} < \mu < \bar{\mu} \end{cases} \quad (13)$$

$$\bar{\phi}_t^s = \bar{\phi}^s y_t, \text{ with } \bar{\phi}^s = \varepsilon^* + \phi^s \quad (14)$$

$$\phi_t^m = Z \frac{y_t}{A_t^m} \quad (15)$$

$$p_t = \frac{\bar{\phi}^s}{Z} A_t^m \quad (16)$$

where

$$Z = \frac{\alpha G(\varepsilon^*) A_I^s + A_D^s}{\alpha [1 - G(\varepsilon^*)]} (\varepsilon^* + \phi^s) \quad (17)$$

and for any $\mu \in (\bar{\beta}, \bar{\mu})$, $\varepsilon^* \in (\varepsilon_L, \varepsilon_H)$ is the unique solution to

$$\frac{(1 - \bar{\beta}\delta) \int_{\varepsilon^*}^{\varepsilon_H} (\varepsilon - \varepsilon^*) dG(\varepsilon)}{\varepsilon^* + \bar{\beta}\delta \left[\bar{\varepsilon} - \varepsilon^* + \alpha\theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right] \mathbb{I}_{\{\hat{\mu} < \mu\}}} - \frac{\mu - \bar{\beta}}{\bar{\beta}\alpha\theta} = 0. \quad (18)$$

(v) (a) As $\mu \rightarrow \bar{\mu}$, $\varepsilon^* \rightarrow \varepsilon_L$ and $\phi_t^s \rightarrow \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta} \bar{\varepsilon} y_t$. (b) As $\mu \rightarrow \bar{\beta}$, $\varepsilon^* \rightarrow \varepsilon_H$ and $\phi_t^s \rightarrow \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta} \varepsilon_H y_t$.

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, $\phi^s = \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta} \bar{\varepsilon} y$, 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, ε^* , 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, ε^* , is strictly decreasing in the rate of inflation, i.e., $\frac{\partial \varepsilon^*}{\partial \mu} < 0$ for $\mu \in (\bar{\beta}, \hat{\mu})$ and for $\mu \in (\hat{\mu}, \bar{\mu})$ (see Corollary 3 in the appendix). Intuitively, the real value of money falls as μ increases, so the marginal investor type, ε^* , 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., $A_{Dt}^m = 0$ and $A_{It}^m = A_t^m$. 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 $\mu \in (\bar{\beta}, \hat{\mu})$, then only dealers hold equity shares overnight, that is, $\tilde{A}_{Dt+1}^s = A^s$ and $\tilde{A}_{It+1}^s = 0$ 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., $\tilde{A}_{Dt+1}^s = 0$ and $\tilde{A}_{It+1}^s = A^s$ so strictly speaking, in this case dealers only provide brokerage services in the OTC market. The intuition for this result is as follows.⁴ For dealers, the return from holding equity overnight is given by the resale price in the OTC market. If inflation is low, ε_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 ε_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 return from holding equity overnight than dealers. For example, as $\mu \rightarrow \bar{\mu}$ we have $\varepsilon_t^* \rightarrow \varepsilon_L$, so the dealer's expected return from holding equity overnight is $\frac{(\varepsilon_L + \phi^s)\bar{\gamma}}{\phi^s}$, while the investor's is $\frac{(\bar{\varepsilon} + \phi^s)\bar{\gamma}}{\phi^s}$.

Given the marginal valuation type, ε^* , 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, ϕ_t^s , 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, ϕ_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 $\bar{\mu}$, ε^* approaches the lower bound of the type distribution, ε_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 μ decreases toward $\bar{\beta}$, ε^* increases toward the upper bound of the type distribution, ε_H , so only investors with the highest valuation type purchase equity in the OTC market (all other investors wish to sell it). Moreover, since $\bar{\beta} < \hat{\mu}$, as $\mu \rightarrow \bar{\beta}$ only dealers hold equity overnight. Thus we have the following result.

⁴See Lagos and Zhang (2015) for a more detailed discussion.

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

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 $k = 0, 1, 2, \dots, N$ (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

$$\iota = \frac{\mu}{\bar{\beta}} - 1 \quad (19)$$

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., $\iota = 0$ for all contingencies at all dates.

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

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

with

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

Given ε^* , 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 ι (or equivalently, the inflation rate μ) increases, equilibrium real money balances decline and the marginal investor type, ε^* , 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 ϕ^s and $\bar{\phi}^s$) smaller. Naturally, the real value of money, ϕ_t^m , 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, ϕ_t^s , real balances, $\phi_t^m A_t^m$, and the price level, ϕ_t^m , for different values of μ .

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

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, ϕ^s and $\bar{\phi}^s$, are increasing in α and θ .⁵ If α increases, money becomes more valuable (both Z and

⁵This 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).

ϕ_t^m increase), provided we focus on a regime in which only investors carry equity overnight.⁶ Proposition 4 formalizes these ideas. The bottom row of Figure ?? illustrates the time paths of the ex-dividend equity price, ϕ_t^s , real balances $\phi_t^m A_t^m$, and the price level, ϕ_t^m for two different values of α .

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

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.

5.2.1 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_D^s , is nonincreasing in the inflation rate. (ii) For any μ close to $\bar{\beta}$, dealers' provision of liquidity by accumulating assets is nonmonotonic in $\alpha\theta$, i.e., $A_D^s = 0$ for $\alpha\theta$ close to 0 and close to 1, but $A_D^s > 0$ 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

⁶Real balances can actually fall with α for $\mu \in (\bar{\beta}, \hat{\mu})$.

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 $Q^s = \alpha G(\varepsilon^*) A_I^s$. 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 $\mathcal{V} = Q^b + Q^s$, or equivalently⁷

$$\mathcal{V} = 2\alpha G(\varepsilon^*) A_I^s + A_D^s. \quad (20)$$

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

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

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

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 $k_t(\mathbf{a}_t, \varepsilon)$ 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*, $p_t^a(\varepsilon) = p_t\phi_t^m + (1 - \theta)(\varepsilon - \varepsilon_t^*)y_t$ per share. When an investor with $\varepsilon < \varepsilon_t^*$ wants to sell, the dealer pays him a *bid price*, $p_t^b(\varepsilon) = p_t\phi_t^m - (1 - \theta)(\varepsilon_t^* - \varepsilon)y_t$ per share. Define $\mathcal{S}_t^a(\varepsilon) = \frac{p_t^a(\varepsilon) - p_t\phi_t^m}{p_t\phi_t^m}$ and $\mathcal{S}_t^b(\varepsilon) = \frac{p_t\phi_t^m - p_t^b(\varepsilon)}{p_t\phi_t^m}$, 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 trading with an investor with $\varepsilon > \varepsilon^*$ is

$$\mathcal{S}^a(\varepsilon) = \frac{(1 - \theta)(\varepsilon - \varepsilon^*)}{\varepsilon^* + \phi^s}$$

and the bid spread earned by a dealer when trading with an investor with $\varepsilon < \varepsilon^*$ is

$$\mathcal{S}^b(\varepsilon) = \frac{(1 - \theta)(\varepsilon^* - \varepsilon)}{\varepsilon^* + \phi^s}.$$

The average real spread earned by dealers is $\bar{\mathcal{S}} = \int [\mathcal{S}^a(\varepsilon)\mathbb{I}_{\{\varepsilon^* < \varepsilon\}} + \mathcal{S}^b(\varepsilon)\mathbb{I}_{\{\varepsilon < \varepsilon^*\}}] dG(\varepsilon)$. The change $\bar{\mathcal{S}}$ in response to changes in μ or α is ambiguous in general.⁸

5.3 Speculative premium

According to Proposition 2, in a monetary equilibrium the equity price, ϕ^s , is larger than the expected present discounted value that any agent assigns to the dividend stream, i.e., $\hat{\phi}_t^s \equiv [\bar{\beta}\delta/(1 - \bar{\beta}\delta)]\bar{\varepsilon}y_t$. 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., $\phi_t^s - \hat{\phi}_t^s$, 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

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

⁹It 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

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

$$\mathcal{P} = \begin{cases} \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta} (\varepsilon^* - \bar{\varepsilon}) & \text{if } \bar{\beta} < \mu \leq \hat{\mu} \\ \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta} \alpha\theta \int_{\varepsilon_L}^{\varepsilon^*} G(\varepsilon) d\varepsilon & \text{if } \hat{\mu} < \mu < \bar{\mu}. \end{cases}$$

The speculative premium is positive in any monetary equilibrium, i.e., $\mathcal{P}_t \geq 0$, 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 μ . Since $\partial\varepsilon^*/\partial(\alpha\theta) > 0$ (see the proof of Proposition 4), the speculative premium is increasing in α and θ . 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 α that the investor gets a trading opportunity in an OTC trading round and with the probability θ 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) $\partial\mathcal{P}/\partial\mu < 0$ and $\partial\mathcal{P}/\partial\iota < 0$, and (ii) $\partial\mathcal{P}/\partial(\alpha\theta) > 0$.*

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 same is true of changes in the bargaining power. The positive correlation between trade

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.

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 $\mathcal{R}_t^s = \left(\frac{P_t^s + D_t^s}{P_{t-1}^s} - 1 \right) \times 100$, where P_t^s is the ex-dividend dollar price of stock s on day t and D_t^s 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., $\mathcal{T}_t^s = \mathcal{V}_t^s / A_t^s$, where $\mathcal{V}_t^s$ is the trade volume of stock s on day t (measured as the total number of shares traded) and A_t^s 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., $\mathcal{R}_t^I = \frac{1}{n} \sum_{s=1}^n \mathcal{R}_t^s$ and $\mathcal{T}_t^I = \frac{1}{n} \sum_{s=1}^n \mathcal{T}_t^s$ 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).¹⁰ Specifically, we use the

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

3-Month Eurodollar futures rate produced by the CME 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, 2001.¹¹ 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 obtained from the website of the Board of Governors of the Federal Reserve System.¹² The sample we use includes between 1300 and 1800 stocks (depending on the time period) and 73 policy dates.¹³

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 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-

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.

¹²The 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.

¹³Our 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.

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 $\Delta i_t \equiv i_t - i_{t-1}$. The event-study analysis consists of running the following regression

$$\mathcal{R}_t^I = a + b\Delta i_t + \epsilon_t \quad (21)$$

for $t \in S_1$, where ϵ_t is an exogenous shock to the asset price.¹⁴ 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, Δi_t , and the stock-market return, $\mathcal{R}_t^I$, are jointly determined by

$$\Delta i_t = \kappa \mathcal{R}_t^I + \varpi x_t + \epsilon_t \quad (22)$$

$$\mathcal{R}_t^I = \rho \Delta i_t + x_t + \eta_t \quad (23)$$

where ϵ_t is a monetary policy shock and η_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 ϵ_t and η_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 ρ . Let Σ_y denote the variance of some variable y . If (22) and (23) were the true model and one were to run an OLS regression

¹⁴In 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).

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 $\Delta i_t = \frac{1}{1-\rho\kappa} [\epsilon_t + \kappa\eta_t + (\kappa + \varpi)x_t]$ and $\mathcal{R}_t^I = \frac{1}{1-\rho\kappa} [\rho\epsilon_t + \eta_t + (1 + \rho\varpi)x_t]$. Let Ω^k denote the covariance matrix of Δi_t and $\mathcal{R}_t^I$ 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 $\Omega_{11}^k \equiv \Sigma_\epsilon^k + \kappa^2 \Sigma_\eta^k + (\kappa + \varpi)^2 \Sigma_x^k$, $\Omega_{12}^k = \Omega_{21}^k \equiv \rho \Sigma_\epsilon^k + \kappa \Sigma_\eta^k + (\kappa + \varpi)(1 + \rho\varpi) \Sigma_x^k$, $\Omega_{22}^k \equiv \rho^2 \Sigma_\epsilon^k + \Sigma_\eta^k + (1 + \rho\varpi)^2 \Sigma_x^k$, and Σ_x^k denotes the variance of variable x in subsample S_k , for $k \in \{0, 1\}$. Provided $\Sigma_x^1 = \Sigma_x^0$ and $\Sigma_\eta^1 = \Sigma_\eta^0$,

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

Hence if $\Sigma_\epsilon^1 - \Sigma_\epsilon^0 > 0$, then ρ can be identified from the difference in the covariance matrices of the two subsamples. This suggests a natural way to estimate ρ . Replace Ω^1 and Ω^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 ρ can be estimated by $\hat{\Omega}_{12}/\hat{\Omega}_{11} \equiv \hat{\rho}$. Rigobon and Sack (2004) show that this estimate can be obtained by regressing $\mathcal{R}_t^I$ on Δi_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 Δi_t is 3.53 basis points (bps) in subsample S_0 and 6.84 bps in subsample S_1 . The standard deviation of $\mathcal{R}_t^I$ is 49.67 bps in subsample S_0 and 64.22 bps in subsample S_1 . The correlation between Δi_t and $\mathcal{R}_t^I$ 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.¹⁵ The point estimate for ρ 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.¹⁶

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 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 ρ in (22)-(23), but using the daily turnover rate (averaged over all traded stocks), $\mathcal{T}_t^I$, as dependent variable instead of the average stock return, $\mathcal{R}_t^I$.

The mean and standard deviation of $\mathcal{T}_t^I$ over the whole sample are 37.291 bps, and 8.52 bps, respectively. The standard deviation of $\mathcal{T}_t^I$ is 8.03 bps in subsample S_0 and 8.72 bps in subsample S_1 . The correlation between Δi_t and $\mathcal{T}_t^I$ 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 marketwide turnover rate on the day of the policy announcement equal to $-.0025$.¹⁷ The daily marketwide turnover rate for our sample

¹⁵The 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.

¹⁶The 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.

¹⁷The R^2 indicates that 15 percent of the variance of the daily turnover rate in days of FOMC policy an-

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 marketwide turnover rate on the day of the policy announcement of about .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 marketwide turnover rate of about 1.3 percent of its typical level.

6.3 Cross-sectional evidence

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 $\mathcal{T}_t^s$ 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 $\mathcal{T}_t^s$ ranked between the $[5(i-1)]^{\text{th}}$ percentile and $(5i)^{\text{th}}$ percentile to the i^{th} portfolio, for $i = 1, \dots, 20$. 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 $(i-1)^{\text{th}}$ 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

nouncements is associated with unexpected changes in monetary policy.

¹⁸Our 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.

¹⁹With 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.

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, 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 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.²¹ 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.²² 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, Δi_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 $\mathcal{T}_t^s$ is the

²⁰The 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.

²¹With 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.

²²The 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.

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 Δi and $\mathcal{T}$ denote the sample averages of Δi_t and $\mathcal{T}_t^s$, respectively, and define $\overline{\mathcal{T}_t^s} \equiv (\mathcal{T}_t^s - \mathcal{T})$ and $\overline{\Delta i_t} \equiv (\Delta i_t - \Delta i)$. The regression we fit is

$$\begin{aligned} \mathcal{R}_t^s = & \beta_0 + \beta_1 \Delta i_t + \beta_2 \mathcal{T}_t^s + \beta_3 \overline{\mathcal{T}_t^s} \times \overline{\Delta i_t} \\ & + D_s + D_t + \beta_4 (\Delta i_t)^2 + \beta_5 (\mathcal{T}_t^s)^2 + \varepsilon_{st}, \end{aligned} \quad (24)$$

where D_s is a stock fixed effect, D_t is a quarterly time dummy, and ε_{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 $\overline{\mathcal{T}_t^s} \times \overline{\Delta i_t}$ 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 β_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 β_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, $\overline{\mathcal{T}_t^s} \times \overline{\Delta i_t}$. 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 $(\mathcal{T}_t^s)^2$ to specification (II), (III), (IV), and (V), respectively. In all specifications, all estimates are significant at 1% level.

The estimate of β_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.²³ Combined, the estimates of β_1 and β_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.

²³ Average daily turnover in our sample is .0035.

The estimate of interest, β_3 , is large and negative in all specifications, ranging from -415 (specification (VII)) to -100 (specification (IV)). The negative and statistically significant estimates of β_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 β_3 is -410 , implying that a 1 pp increase in the policy rate reduces the announcement-day return by $\beta_1 + 2\beta_4 + \beta_3 (\mathcal{T}_t^A - \mathcal{T}) \approx -8$ pps for equity A and by $\beta_1 + 2\beta_4 + \beta_3 (\mathcal{T}_t^B - \mathcal{T}) \approx -4$ 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 quantitatively important channel that transmits monetary policy shocks to asset prices.

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., $\{i_t, \mathcal{R}_t^I, \mathcal{T}_t^I\}_{t \in S_0 \cup S_1}$, where i_t , $\mathcal{R}_t^I$, and $\mathcal{T}_t^I$ are the daily measures of the policy rate, the stock return, and turnover described in Sections 6.1 and 6.2. The lag length is set to 10.²⁴ To identify the effects of monetary policy shocks we apply an identification scheme based on an external high-frequency instrument.²⁵

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

²⁴The 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).

²⁵See 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 Hamilton (2003), Kilian (2008a,b), Stock and Watson (2012), Mertens and Ravn (2013), and Gertler and Karadi (2015).

computed using a recursive wild bootstrap based on 10,000 replications.²⁶ The top and bottom rows show responses for forecast horizons of 30 days and 1,000 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 return falls by -4.02 pps. Notice that the size and magnitude of this decrease in stock return on the day of the policy shock is 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, in response to the 1 pp unexpected increase in the nominal rate, the turnover rate falls by -0.0025 bps. This is the same point estimate we obtained in the event-study regression reported in Table 1. According to the point estimates it takes about 2 days 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 40 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 empirical findings in Table ???. 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.

²⁶The 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.

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 $s \in \mathbb{N} = \{1, 2, \dots, N\}$. 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- t 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 α^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.²⁷ 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 $\{a_{t+1}^s, a_{t+1}^{ms}\}_{s \in \mathbb{N}}$, where a_{t+1}^s denotes the holding of asset s , and a_{t+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 $\sigma_{ij} = \Pr(\mu_{t+1} = \mu_j | \mu_t = \mu_i)$ and $\mu_i \in \mathbb{R}_{++}$ for all $i, j \in \mathbb{M} = \{0, 1, \dots, M\}$. The realization of μ_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, $\mathbf{x}_t = (A_t^m, y_t, \mu_t) \in \mathbb{R}_+^3$. That is, $\phi_t^s = \phi^s(\mathbf{x}_t)$, $\bar{\phi}_t^s = \bar{\phi}^s(\mathbf{x}_t)$, $\phi_t^m = \phi^m(\mathbf{x}_t)$, $p_t^s = p^s(\mathbf{x}_t)$, and $\varepsilon_t^{s*} = \varepsilon^{s*}(\mathbf{x}_t)$. We conjecture the recursive equilibrium has the property that real prices are linear functions of the aggregate dividend, i.e., suppose $\mathbf{x}_t = (A_t^m, y_t, \mu_t)$, then $\phi^s(\mathbf{x}_t) = \phi_i^s y_t$, $\bar{\phi}^s(\mathbf{x}_t) \equiv p^s(\mathbf{x}_t) \phi^m(\mathbf{x}_t) = \bar{\phi}_i^s y_t$, $\phi^m(\mathbf{x}_t) A_t^m = Z_i y_t$, $\varepsilon^{s*}(\mathbf{x}_t) \equiv [\bar{\phi}^s(\mathbf{x}_t) - \phi^s(\mathbf{x}_t)] / y_t = \bar{\phi}_i^s - \phi_i^s \equiv \varepsilon_i^{s*}$, and $\phi^m(\mathbf{x}_t) A_t^{ms} = Z_i^s y_t$, 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 $\{\varepsilon_i^{s*}, \phi_i^s, Z_i^s, Z_i\}_{i \in \mathbb{M}, s \in \mathbb{N}}$ of $M(3N + 1)$ unknowns that solves the following system of $M(3N + 1)$

²⁷In 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.

equations

$$\phi_i^s = \bar{\beta} \delta \sum_{j \in \mathbb{M}} \sigma_{ij} \left[\bar{\varepsilon} + \phi_j^s + \alpha^s \theta \int_{\varepsilon_L}^{\varepsilon_j^{s*}} (\varepsilon_j^{s*} - \varepsilon) dG(\varepsilon) \right] \text{ for all } (i, s) \in \mathbb{M} \times \mathbb{N} \quad (25)$$

$$Z_i = \frac{\bar{\beta}}{\mu_i} \sum_{j \in \mathbb{M}} \sigma_{ij} \left[Z_j + \alpha^s \theta \int_{\varepsilon_j^{s*}}^{\varepsilon_H} (\varepsilon - \varepsilon_j^{s*}) dG(\varepsilon) \frac{Z_j}{\varepsilon_j^{s*} + \phi_j^s} \right] \text{ for all } (i, s) \in \mathbb{M} \times \mathbb{N} \quad (26)$$

$$Z_i^s = \frac{G(\varepsilon_i^{s*}) A^s}{1 - G(\varepsilon_i^{s*})} (\varepsilon_i^{s*} + \phi_i^s) \text{ for all } (i, s) \in \mathbb{M} \times \mathbb{N} \quad (27)$$

$$Z_i = \sum_{s \in \mathbb{N}} Z_i^s \text{ for all } i \in \mathbb{M}. \quad (28)$$

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 section.

The return of stock s at date $t + 1$ is $\mathcal{R}_{t+1}^s = \bar{\phi}_{t+1}^s / \phi_t^s - 1$, where $\bar{\phi}_t^s \equiv p_t \phi_t^m = \phi_t^s + \varepsilon_t^* y_t$ 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 $\mathbf{x}_t = (A_t^m, y_t, \mu_i)$ and at date $t + 1$ is $\mathbf{x}_{t+1} = (\mu_i A_t^m, y_{t+1}, \mu_j)$, then

$$\mathcal{R}_{t+1}^s = \frac{\phi_j^s + \varepsilon_j^{s*}}{\phi_i^s} \frac{y_{t+1}}{y_t} - 1.$$

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 κA^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 $\mathcal{V}_t^s = 2\alpha^s G(\varepsilon_t^{s*}) \kappa A^s$. 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

$$\mathcal{T}_t^s = \mathcal{V}_t^s / A^s = 2\alpha^s G(\varepsilon_t^{s*}) \kappa.$$

Naturally, a nonzero fraction of inactive stocks (i.e., $\kappa < 1$) lowers the *measured* turnover rate.²⁸

²⁸The first column labeled “Turnover” in Table 2 reports the annual turnover rates corresponding to each of

In a recursive equilibrium, suppose the state at date t is $\mathbf{x}_t = (A_t^m, y_t, \mu_i)$, then the turnover rate can be written as $\mathcal{T}_i^s = 2\alpha^s G(\varepsilon_i^{s*}) \kappa$.

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., $\mathcal{R}_t^I = \frac{1}{N} \sum_{s \in \mathbb{N}} \mathcal{R}_t^s$ and $\mathcal{T}_t^I = \frac{1}{N} \sum_{s \in \mathbb{N}} \mathcal{T}_t^s$ are the average return and the average turnover rate for the universe of stocks in the theory.

Let $\psi^b(\mathbf{x}_t)$ denote the state- $\mathbf{x}_t$ 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 $\psi^b(\mathbf{x}_t) = \beta \mathbb{E}[\phi^m(\mathbf{x}_{t+1}) | \mathbf{x}_t]$. The dollar price of the asset in the second subperiod of period t is $q(\mathbf{x}_t) \equiv \psi^b(\mathbf{x}_t) / \phi^m(\mathbf{x}_t)$, so the Euler equation can be written as $q(\mathbf{x}_t) = \beta / \bar{\pi}(\mathbf{x}_t)$, where $\bar{\pi}(\mathbf{x}_t) \equiv \frac{\phi^m(\mathbf{x}_t)}{\mathbb{E}[\phi^m(\mathbf{x}_{t+1}) | \mathbf{x}_t]}$. Then the (net) nominal rate on this bond (between period t and period $t+1$) is $r(\mathbf{x}_t) \equiv q(\mathbf{x}_t)^{-1} - 1 = \bar{\pi}(\mathbf{x}_t) / \beta - 1$. Suppose $\mathbf{x}_t = (A_t^m, y_t, \mu_i)$, then in a recursive equilibrium, $\bar{\pi}(\mathbf{x}_t) \equiv \bar{\pi}_i$ and $r(\mathbf{x}_t) \equiv r_i = \bar{\pi}_i / \beta - 1$, where $\bar{\pi}_i = \frac{\mu_i}{\bar{\gamma} \sum_{j \in \mathbb{M}} \sigma_{ij} Z_j}$. So the one-period risk-free nominal interest rate between time t in state $\mathbf{x}_t = (A_t^m, y_t, \mu_i)$ and time $t+1$ is

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

7.2 Calibration

We think of one model period as being one day. The discount factor, β , 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 δ 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 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 $\kappa < 1$.

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 $s \in \{1, \dots, 19\}$ in the model, α^s is calibrated so that the long-run time-average of the equilibrium turnover rate, i.e., $\bar{\mathcal{T}}_t^s \equiv \lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T \mathcal{T}_t^s$, 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, κ , 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 $\frac{1}{20} \sum_{s=1}^{20} \bar{\mathcal{T}}_t^s = .0035$.²⁹

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., $\{\mu_i, \sigma_{ij}\}_{i,j \in \mathbb{M}}$ 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 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, $\{r_i, \sigma_{ij}\}_{i,j=1}^7$.³⁰ 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 σ_{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.

²⁹This procedure delivers $\alpha^1 = .0952$, $\alpha^2 = .1171$, $\alpha^3 = .1344$, $\alpha^4 = .1506$, $\alpha^5 = .1665$, $\alpha^6 = .1822$, $\alpha^7 = .1977$, $\alpha^8 = .2135$, $\alpha^9 = .2296$, $\alpha^{10} = .2467$, $\alpha^{11} = .2654$, $\alpha^{12} = .2849$, $\alpha^{13} = .3076$, $\alpha^{14} = .3341$, $\alpha^{15} = .3658$, $\alpha^{16} = .4051$, $\alpha^{17} = .4561$, $\alpha^{18} = .5287$, $\alpha^{19} = .6520$, and $\kappa = .03$.

³⁰Specifically, the process we estimate is $\ln i_t = (1 - \xi)i_0 + \xi \ln i_{t-1} + \varepsilon_t$, where ε_t is Gaussian white noise. With i_t denominated in basis points, the estimate of ξ is 0.9997652, the estimate of i_0 is 5.7362, and the estimate of the standard deviation of ε_t is .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).

7.3 Exercise 1: 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 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 estimate of $-.0025$ obtained in Section 6.2. These comparisons are 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: Cross-sectional implications

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.³¹ 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

³¹The 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.

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 impulse responses from the data, as described in Section 6.4 and Appendix B.1.³²

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, and falls within the 95% confidence intervals of the empirical impulse responses for the first 120 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 -2.57 pps, which is somewhat smaller than the empirical estimate of -4.02 pps. For the first 10 days the theoretical impulse response is quite close to the empirical estimates in the sense that it 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 two 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

³²For 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.

turnover rate falls by $-.0001$ in the model, which, consistent with the findings in Section 7.3, is about two orders of magnitude smaller than the $-.0025$ bps estimated from the data. 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 path for the theoretical turnover rate becomes very close to the empirical path after about 80 days, and remains below the empirical path for horizons longer than 100 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.³³

³³Figure 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.

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

$$\begin{aligned} \max_{\{\tilde{a}_{Dt}, \tilde{a}_{It}, a'_{It}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\alpha \int_{\varepsilon_L}^{\varepsilon_H} \varepsilon a'_{It} (d\varepsilon) + (1 - \alpha) \bar{\varepsilon} a_{It} \right] y_t \\ \text{s.t. (1), (4), (5), and } \alpha \int_{\varepsilon_L}^{\varepsilon_H} a'_{It} (d\varepsilon) \leq a_{Dt} + \alpha a_{It}. \end{aligned}$$

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

$$\bar{W}^* = \max_{\{\tilde{a}_{Dt}, \tilde{a}_{It}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t [\varepsilon_H (\tilde{a}_{Dt} + \alpha \tilde{a}_{It}) + (1 - \alpha) \bar{\varepsilon} \tilde{a}_{It}] \delta y_t + w$$

s.t. (1), where $w \equiv [\alpha \varepsilon_H + (1 - \alpha) \bar{\varepsilon}] (1 - \delta) A^s \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t y_t$. Rearrange the expression for $\bar{W}^*$ and substitute (1) (at equality) to obtain

$$\begin{aligned} \bar{W}^* &= \max_{\{\tilde{a}_{It}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \{ \varepsilon_H A^s - (1 - \alpha) (\varepsilon_H - \bar{\varepsilon}) \tilde{a}_{It} \} \delta y_t + w \\ &= \{ \delta \varepsilon_H + (1 - \delta) [\alpha \varepsilon_H + (1 - \alpha) \bar{\varepsilon}] \} A^s \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t y_t. \end{aligned}$$

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

$$W_t^D(\mathbf{a}_t, k_t) = \boldsymbol{\phi}_t \mathbf{a}_t + k_t + \bar{W}_t^D$$

where

$$\bar{W}_t^D \equiv \max_{\tilde{\mathbf{a}}_{t+1} \in \mathbb{R}_+^2} [-\boldsymbol{\phi}_t \tilde{\mathbf{a}}_{t+1} + \beta \mathbb{E}_t V_{t+1}^D(\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s)], \quad (30)$$

so (7) implies

$$\begin{aligned} \hat{W}_t^D(\mathbf{a}_t, k_t) &= k_t + \bar{W}_t^D + \max_{\hat{\mathbf{a}}_t \in \mathbb{R}_+^2} \boldsymbol{\phi}_t \hat{\mathbf{a}}_t \\ \text{s.t. } \hat{a}_t^m + p_t \hat{a}_t^s &\leq a_t^m + p_t a_t^s. \end{aligned}$$

Hence

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

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

and

$$\hat{W}_t^D(\mathbf{a}_t, k_t) = \max(\phi_t^m, \phi_t^s/p_t) (a_t^m + p_t a_t^s) + k_t + \bar{W}_t^D. \quad (31)$$

Also, notice that (9) implies

$$W_t^I(\mathbf{a}_t, -k_t) = \phi_t \mathbf{a}_t - k_t + \bar{W}_t^I \quad (32)$$

where

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

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

$$\max_{\bar{a}_t^m, k_t} \left[(\varepsilon_t^* - \varepsilon) (\bar{a}_t^m - a_{it}^m) \frac{1}{p_t} y_t - k_t \right]^\theta k_t^{1-\theta}$$

$$\text{s.t. } 0 \leq k_t \leq (\varepsilon_t^* - \varepsilon) (\bar{a}_t^m - a_{it}^m) \frac{1}{p_t} y_t$$

with $\bar{a}_t^s = a_{it}^s + (1/p_t) (a_{it}^m - \bar{a}_t^m)$. Hence

$$\bar{a}_t^m(\mathbf{a}_{it}, \varepsilon) \begin{cases} = a_{it}^m + p_t a_{it}^s & \text{if } \varepsilon < \varepsilon_t^* \\ \in [0, a_{it}^m + p_t a_{it}^s] & \text{if } \varepsilon = \varepsilon_t^* \\ = 0 & \text{if } \varepsilon_t^* < \varepsilon, \end{cases}$$

$$\bar{a}_t^s(\mathbf{a}_{it}, \varepsilon) = a_{it}^s + (1/p_t) [a_{it}^m - \bar{a}_t^m(\mathbf{a}_{it}, \varepsilon)],$$

and

$$k_t(\mathbf{a}_{it}, \varepsilon) = (1-\theta) (\varepsilon - \varepsilon_t^*) \left[\mathbb{I}_{\{\varepsilon_t^* < \varepsilon\}} \frac{1}{p_t} a_{it}^m - \mathbb{I}_{\{\varepsilon < \varepsilon_t^*\}} a_{it}^s \right] y_t.$$

This concludes the proof. ■

Lemma 2 Let $(\tilde{a}_{dt+1}^m, \tilde{a}_{dt+1}^s)$ and $(\tilde{a}_{it+1}^m, \tilde{a}_{it+1}^s)$ 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:

$$\phi_t^m \geq \beta \mathbb{E}_t \max(\phi_{t+1}^m, \phi_{t+1}^s/p_{t+1}), \text{ with “} = \text{” if } \tilde{a}_{dt+1}^m > 0 \quad (34)$$

$$\phi_t^s \geq \beta \delta \mathbb{E}_t \max(p_{t+1} \phi_{t+1}^m, \phi_{t+1}^s), \text{ with “} = \text{” if } \tilde{a}_{dt+1}^s > 0 \quad (35)$$

$$\phi_t^m \geq \beta \mathbb{E}_t \left[\phi_{t+1}^m + \alpha \theta \int_{\varepsilon_{t+1}^*}^{\varepsilon_H} (\varepsilon - \varepsilon_{t+1}^*) y_{t+1} dG(\varepsilon) \frac{1}{p_{t+1}} \right], \text{ with “} = \text{” if } \tilde{a}_{dt+1}^m > 0 \quad (36)$$

$$\phi_t^s \geq \beta \delta \mathbb{E}_t \left[\bar{\varepsilon} y_{t+1} + \phi_{t+1}^s + \alpha \theta \int_{\varepsilon_L}^{\varepsilon_{t+1}^*} (\varepsilon_{t+1}^* - \varepsilon) y_{t+1} dG(\varepsilon) \right], \text{ with “} = \text{” if } \tilde{a}_{dt+1}^s > 0. \quad (37)$$

Proof. With Lemma 1, we can write $V_t^I(\mathbf{a}_t, \varepsilon)$ as

$$\begin{aligned} V_t^I(\mathbf{a}_t, \varepsilon) = & \left[\alpha \theta (\varepsilon - \varepsilon_t^*) \mathbb{I}_{\{\varepsilon_t^* < \varepsilon\}} \frac{1}{p_t} y_t + \phi_t^m \right] a_t^m \\ & + \left\{ \left[\varepsilon + \alpha \theta (\varepsilon_t^* - \varepsilon) \mathbb{I}_{\{\varepsilon < \varepsilon_t^*\}} \right] y_t + \phi_t^s \right\} a_t^s + \bar{W}_t^I \end{aligned} \quad (38)$$

and $V_t^D(\mathbf{a}_t)$ as

$$V_t^D(\mathbf{a}_t) = \alpha \int k_t(\mathbf{a}_{it}, \varepsilon) dH_{It}(\mathbf{a}_{it}, \varepsilon) + \max(\phi_t^m, \phi_t^s/p_t) (a_t^m + p_t a_t^s) + \bar{W}_t^D.$$

Since ε is i.i.d. over time, $W_t^I(\mathbf{a}_t)$ is independent of ε and the portfolio that each investor chooses to carry into period $t+1$ is independent of ε . Therefore we can write $dH_{It}(\mathbf{a}_t, \varepsilon) = dF_{It}(\mathbf{a}_t) dG(\varepsilon)$, 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

$$V_t^D(\mathbf{a}_t) = \max(\phi_t^m, \phi_t^s/p_t) (a_t^m + p_t a_t^s) + V_t^D(\mathbf{0}) \quad (39)$$

where

$$V_t^D(\mathbf{0}) = \alpha (1 - \theta) \int (\varepsilon - \varepsilon_t^*) \left[\mathbb{I}_{\{\varepsilon_t^* < \varepsilon\}} \frac{1}{p_t} A_{It}^m - \mathbb{I}_{\{\varepsilon < \varepsilon_t^*\}} A_{It}^s \right] dG(\varepsilon) y_t + \bar{W}_t^D.$$

From (39) we have

$$V_{t+1}^D(\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s) = \max(\phi_{t+1}^m, \phi_{t+1}^s/p_{t+1}) (\tilde{a}_{t+1}^m + p_{t+1} \delta \tilde{a}_{t+1}^s) + V_{t+1}^D(\mathbf{0})$$

and from (38) we have

$$\begin{aligned} \int V_{t+1}^I[\tilde{a}_{t+1}^m, \delta \tilde{a}_{t+1}^s + (1 - \delta) A^s, \varepsilon] = & \left[\alpha \theta \int_{\varepsilon_{t+1}^*}^{\varepsilon_H} (\varepsilon - \varepsilon_{t+1}^*) dG(\varepsilon) \frac{1}{p_{t+1}} y_{t+1} + \phi_{t+1}^m \right] \tilde{a}_{t+1}^m \\ & + \delta \left\{ \left[\bar{\varepsilon} + \int_{\varepsilon_L}^{\varepsilon_{t+1}^*} \alpha \theta (\varepsilon_{t+1}^* - \varepsilon) dG(\varepsilon) \right] y_{t+1} + \phi_{t+1}^s \right\} \tilde{a}_{t+1}^s + \zeta_{t+1} \end{aligned}$$

where $\zeta_{t+1} \equiv \left\{ \left[\varepsilon + \alpha \theta (\varepsilon_{t+1}^* - \varepsilon) \mathbb{I}_{\{\varepsilon < \varepsilon_{t+1}^*\}} \right] y_{t+1} + \phi_{t+1}^s \right\} (1 - \delta) A^s + \bar{W}_{t+1}^I$. 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*

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

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

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

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

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

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, $\{\bar{\mathbf{a}}_t, k_t\}_{t=0}^\infty$, dealer portfolios, $\{\langle \hat{\mathbf{a}}_{dt}, \bar{\mathbf{a}}_{dt+1}, \mathbf{a}_{dt+1} \rangle_{d \in \mathcal{D}}\}_{t=0}^\infty$, and investor portfolios, $\{\langle \bar{\mathbf{a}}_{it+1}, \mathbf{a}_{it+1} \rangle_{i \in \mathcal{I}}\}_{t=0}^\infty$, 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*

$$\begin{aligned} k_t(\mathbf{a}_t, \varepsilon) &= (1 - \theta) (\varepsilon - \varepsilon_t^*) \left[\chi(\varepsilon_t^*, \varepsilon) \frac{1}{p_t} a_t^m - [1 - \chi(\varepsilon_t^*, \varepsilon)] a_t^s \right] y_t \\ \bar{a}_t^m(\mathbf{a}_t, \varepsilon) &= [1 - \chi(\varepsilon_t^*, \varepsilon)] (a_t^m + p_t a_t^s) \\ \bar{a}_t^s(\mathbf{a}_t, \varepsilon) &= \chi(\varepsilon_t^*, \varepsilon) (1/p_t) (a_t^m + p_t a_t^s) \\ \hat{\mathbf{a}}_t(\mathbf{a}_t) &= \bar{\mathbf{a}}_t(\mathbf{a}_t, 0). \end{aligned}$$

(ii) *Interdealer market clearing*

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

where $A_{jt}^m \equiv \int a_t^m dF_{jt}(\mathbf{a}_t)$ and $A_{jt}^s \equiv \int a_t^s dF_{jt}(\mathbf{a}_t)$ for $j \in \{D, I\}$.

(iii) *Optimal end-of-period portfolios:*

$$\begin{aligned}
\phi_t^m &\geq \beta \mathbb{E}_t \max(\phi_{t+1}^m, \phi_{t+1}^s / p_{t+1}) \\
\phi_t^s &\geq \beta \delta \mathbb{E}_t \max(p_{t+1} \phi_{t+1}^m, \phi_{t+1}^s) \\
\phi_t^m &\geq \beta \mathbb{E}_t \left[\phi_{t+1}^m + \alpha \theta \int_{\varepsilon_{t+1}^*}^{\varepsilon_H} (\varepsilon - \varepsilon_{t+1}^*) dG(\varepsilon) \frac{1}{p_{t+1}} y_{t+1} \right] \\
\phi_t^s &\geq \beta \delta \mathbb{E}_t \left[\bar{\varepsilon} y_{t+1} + \phi_{t+1}^s + \alpha \theta \int_{\varepsilon_L}^{\varepsilon_{t+1}^*} (\varepsilon_{t+1}^* - \varepsilon) y_{t+1} dG(\varepsilon) \right]
\end{aligned}$$

with

$$\begin{aligned}
[\phi_t^m - \beta \mathbb{E}_t \max(\phi_{t+1}^m, \phi_{t+1}^s / p_{t+1})] \tilde{a}_{dt+1}^m &= 0 \\
[\phi_t^s - \beta \delta \mathbb{E}_t \max(p_{t+1} \phi_{t+1}^m, \phi_{t+1}^s)] \tilde{a}_{dt+1}^s &= 0 \\
\left\{ \phi_t^m - \beta \mathbb{E}_t \left[\phi_{t+1}^m + \alpha \theta \int_{\varepsilon_{t+1}^*}^{\varepsilon_H} (\varepsilon - \varepsilon_{t+1}^*) dG(\varepsilon) \frac{1}{p_{t+1}} y_{t+1} \right] \right\} \tilde{a}_{it+1}^m &= 0 \\
\left\{ \phi_t^s - \beta \delta \mathbb{E}_t \left[\bar{\varepsilon} y_{t+1} + \phi_{t+1}^s + \alpha \theta \int_{\varepsilon_L}^{\varepsilon_{t+1}^*} (\varepsilon_{t+1}^* - \varepsilon) y_{t+1} dG(\varepsilon) \right] \right\} \tilde{a}_{it+1}^s &= 0
\end{aligned}$$

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

$$\begin{aligned}
a_{jt+1}^m &= \tilde{a}_{jt+1}^m \\
a_{jt+1}^s &= \delta \tilde{a}_{jt+1}^s + \mathbb{I}_{\{j \in \mathcal{I}\}} (1 - \delta) A^s \\
\tilde{a}_{jt+1}^k &\in \mathbb{R}_+ \text{ for } k \in \{s, m\}
\end{aligned}$$

for all $j \in \mathcal{D} \cup \mathcal{I}$.

(iv) *End-of-period market clearing*

$$\begin{aligned}
\tilde{A}_{Dt+1}^s + \tilde{A}_{It+1}^s &= A^s \\
\tilde{A}_{Dt+1}^m + \tilde{A}_{It+1}^m &= A_{t+1}^m
\end{aligned}$$

where $\tilde{A}_{Dt+1}^k \equiv \int_{\mathcal{D}} \tilde{a}_{xt+1}^k dx$ and $\tilde{A}_{It+1}^k \equiv \int_{\mathcal{I}} \tilde{a}_{xt+1}^k dx$ 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 $\Upsilon(\zeta) : \mathbb{R} \rightarrow \mathbb{R}$ by $\Upsilon(\zeta) \equiv \bar{\beta} [1 + \alpha\theta(1 - \bar{\beta}\delta)\zeta]$. Let $\hat{\zeta} \equiv \frac{(1-\alpha\theta)(\bar{\varepsilon}-\varepsilon_L)}{\alpha\theta\bar{\varepsilon}}$ and $\bar{\zeta} \equiv \frac{\bar{\varepsilon}-\varepsilon_L}{\bar{\beta}\delta\bar{\varepsilon}+(1-\bar{\beta}\delta)\varepsilon_L}$, so that $\hat{\mu} = \Upsilon(\hat{\zeta})$ and $\bar{\mu} = \Upsilon(\bar{\zeta})$. Since Υ is strictly increasing, $\hat{\mu} < \bar{\mu}$ if and only if $\hat{\zeta} < \bar{\zeta}$. With (11) and the fact that $\bar{\varepsilon} \equiv \int_{\varepsilon_L}^{\varepsilon_H} \varepsilon dG(\varepsilon) = \varepsilon_H - \int_{\varepsilon_L}^{\varepsilon_H} G(\varepsilon) d\varepsilon$,

$$\hat{\zeta} = \frac{\int_{\hat{\varepsilon}}^{\varepsilon_H} [1 - G(\varepsilon)] d\varepsilon}{\bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^{\hat{\varepsilon}} G(\varepsilon) d\varepsilon},$$

so clearly,

$$\hat{\zeta} < \frac{\int_{\varepsilon_L}^{\varepsilon_H} [1 - G(\varepsilon)] d\varepsilon}{\bar{\varepsilon}} = \frac{\bar{\varepsilon} - \varepsilon_L}{\bar{\varepsilon}} < \bar{\zeta}.$$

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 $d \in \mathcal{D}$ and an investor $i \in \mathcal{I}$ in the time- t Walrasian market are

$$\begin{aligned} \phi_t^s &\geq \beta\delta\mathbb{E}_t\phi_{t+1}^s, \text{ “=” if } \tilde{a}_{t+1d}^s > 0 \\ \phi_t^s &\geq \beta\delta\mathbb{E}_t(\bar{\varepsilon}y_{t+1} + \phi_{t+1}^s), \text{ “=” if } \tilde{a}_{t+1i}^s > 0. \end{aligned}$$

In a stationary equilibrium, $\mathbb{E}_t(\phi_{t+1}^s/\phi_t^s) = \bar{\gamma}$, and $\beta\delta\bar{\gamma} < 1$ is a maintained assumption, so no dealer holds equity. The Walrasian market for equity can only clear if $\phi^s = \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta}\bar{\varepsilon}$. 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

$$\mu \geq \bar{\beta}, \text{ “=” if } \tilde{a}_{dt+1}^m > 0 \quad (41)$$

$$\phi^s \geq \bar{\beta}\delta\bar{\phi}^s, \text{ “=” if } \tilde{a}_{dt+1}^s > 0 \quad (42)$$

$$1 \geq \frac{\bar{\beta}}{\mu} \left[1 + \frac{\alpha\theta}{\varepsilon^* + \phi^s} \int_{\varepsilon^*}^{\varepsilon_H} (\varepsilon - \varepsilon^*) dG(\varepsilon) \right], \text{ “=” if } \tilde{a}_{it+1}^m > 0 \quad (43)$$

$$\phi^s \geq \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta} \left[\bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right], \text{ “=” if } \tilde{a}_{it+1}^s > 0. \quad (44)$$

(We have used the fact that, as will become clear below, $\bar{\phi}^s \equiv \varepsilon^* + \phi^s \geq \varepsilon_L + \phi^s > \phi^s$ in any equilibrium.) Under our maintained assumption $\bar{\beta} < \mu$, (41) implies $\tilde{a}_{dt+1}^m = Z_D = 0$, 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 $d \in \mathcal{D}$ and $\tilde{a}_{it+1}^s > 0$ for some $i \in \mathcal{I}$. The equilibrium conditions for this case are (17) together with

$$\phi^s > \bar{\beta} \delta \bar{\phi}^s \quad (45)$$

$$1 = \frac{\bar{\beta}}{\mu} \left[1 + \frac{\alpha \theta}{\varepsilon^* + \phi^s} \int_{\varepsilon^*}^{\varepsilon_H} (\varepsilon - \varepsilon^*) dG(\varepsilon) \right] \quad (46)$$

$$\phi^s = \frac{\bar{\beta} \delta}{1 - \bar{\beta} \delta} \left[\bar{\varepsilon} + \alpha \theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right] \quad (47)$$

and

$$\tilde{a}_{dt+1}^m = 0 \text{ for all } d \in \mathcal{D} \quad (48)$$

$$\tilde{a}_{it+1}^m \geq 0, \text{ with “} > \text{” for some } i \in \mathcal{I} \quad (49)$$

$$\tilde{a}_{dt+1}^s = 0 \text{ for all } d \in \mathcal{D} \quad (50)$$

$$\tilde{a}_{it+1}^s \geq 0, \text{ with “} > \text{” for some } i \in \mathcal{I}. \quad (51)$$

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

$$1 = \frac{\bar{\beta}}{\mu} \left[1 + \alpha \theta \frac{\int_{\varepsilon^*}^{\varepsilon_H} (\varepsilon - \varepsilon^*) dG(\varepsilon)}{\varepsilon^* + \frac{\bar{\beta} \delta}{1 - \bar{\beta} \delta} \left[\bar{\varepsilon} + \alpha \theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right]} \right] \quad (52)$$

which is a single equation in ε^* . Define

$$T(x) \equiv \frac{\int_x^{\varepsilon_H} (\varepsilon - x) dG(\varepsilon)}{\frac{1}{1 - \bar{\beta} \delta} x + \frac{\bar{\beta} \delta}{1 - \bar{\beta} \delta} \hat{T}(x)} - \frac{\mu - \bar{\beta}}{\bar{\beta} \alpha \theta} \quad (53)$$

with

$$\hat{T}(x) \equiv \bar{\varepsilon} - x + \alpha \theta \int_{\varepsilon_L}^x (x - \varepsilon) dG(\varepsilon), \quad (54)$$

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

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

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

and

$$T'(x) = -\frac{[1-G(x)]\left\{x + \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta}\left[\bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^x G(\varepsilon)d\varepsilon\right]\right\} + \left[\int_x^{\varepsilon_H} [1-G(\varepsilon)]d\varepsilon\right]\left\{1 + \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta}\alpha\theta G(x)\right\}}{\left\{x + \frac{\bar{\beta}\delta}{1-\bar{\beta}\delta}\left[\bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^x G(\varepsilon)d\varepsilon\right]\right\}^2} < 0.$$

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 ε^* , ϕ^s is given by (47). Given ε^* and ϕ^s , the values of Z , $\bar{\phi}^s$, ϕ_t^m and p_t are obtained using (17) (with $A_I^s = A^s$ and $A_D^s = 0$), (14), (15) and (16). To conclude this step notice that for this case to be an equilibrium, (45) must hold, or equivalently, using $\bar{\phi}^s = \varepsilon^* + \phi^s$ 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 $\hat{T}(\bar{\varepsilon}) > 0$, 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

$$\bar{\beta} \left[1 + \frac{(1 - \bar{\beta}\delta) \alpha\theta \int_{\hat{\varepsilon}}^{\varepsilon_H} (\varepsilon - \hat{\varepsilon}) dG(\varepsilon)}{\hat{\varepsilon}} \right] < \mu.$$

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

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

$$\phi^s = \bar{\beta}\delta\bar{\phi}^s \tag{55}$$

$$\phi^s > \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \left[\bar{\varepsilon} + \alpha\theta \int_{\varepsilon_L}^{\varepsilon^*} (\varepsilon^* - \varepsilon) dG(\varepsilon) \right], \text{ “=” if } \tilde{a}_{it+1}^s > 0. \tag{56}$$

$$\tilde{a}_{dt+1}^s \geq 0, \text{ with “>” for some } d \in \mathcal{D} \tag{57}$$

$$\tilde{a}_{it+1}^s = 0, \text{ for all } i \in \mathcal{I}. \tag{58}$$

The conditions (46) and (55) are to be solved for ε^* and ϕ^s . First use $\bar{\phi}^s = \varepsilon^* + \phi^s$ in (55) to obtain

$$\phi^s = \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \varepsilon^*. \quad (59)$$

Substitute (59) in (46) to obtain

$$1 = \frac{\bar{\beta}}{\mu} \left[1 + \frac{\alpha\theta (1 - \bar{\beta}\delta) \int_{\varepsilon^*}^{\varepsilon_H} (\varepsilon - \varepsilon^*) dG(\varepsilon)}{\varepsilon^*} \right] \quad (60)$$

which is a single equation in ε^* . Define

$$R(x) \equiv \frac{(1 - \bar{\beta}\delta) \int_x^{\varepsilon_H} (\varepsilon - x) dG(\varepsilon)}{x} - \frac{\mu - \bar{\beta}}{\bar{\beta}\alpha\theta} \quad (61)$$

and notice that ε^* solves (60) if and only if it satisfies $R(\varepsilon^*) = 0$. R is a continuous real-valued function on $[\varepsilon_L, \varepsilon_H]$, with

$$\begin{aligned} R(\varepsilon_L) &= \frac{(1 - \bar{\beta}\delta) (\bar{\varepsilon} - \varepsilon_L)}{\varepsilon_L} - \frac{\mu - \bar{\beta}}{\bar{\beta}\alpha\theta} \\ R(\varepsilon_H) &= -\frac{\mu - \bar{\beta}}{\bar{\beta}\alpha\theta} \end{aligned}$$

and

$$R'(x) = -\frac{[1 - G(x)]x + \int_x^{\varepsilon_H} [1 - G(\varepsilon)] d\varepsilon}{\frac{1}{1 - \bar{\beta}\delta} x^2} < 0.$$

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 ε^* , ϕ^s is obtained from (59). Given ε^* and ϕ^s , the values of Z , $\bar{\phi}^s$, ϕ_t^m and p_t are obtained using (17) (with $A_D^s = A^s - A_I^s = \delta A^s$), (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

$$\mu < \bar{\beta} \left[1 + \frac{\alpha\theta (1 - \bar{\beta}\delta) \int_{\hat{\varepsilon}}^{\varepsilon_H} (\varepsilon - \hat{\varepsilon}) dG(\varepsilon)}{\hat{\varepsilon}} \right],$$

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 $\tilde{a}_{dt+1}^s > 0$ for some $d \in \mathcal{D}$, and $\tilde{a}_{it+1}^s > 0$ for some $i \in \mathcal{I}$. The equilibrium conditions are (17), (46), (47), (48), (49), and (55) with

$$\tilde{a}_{it+1}^s \geq 0 \text{ and } \tilde{a}_{dt+1}^s \geq 0, \text{ with “} > \text{” for some } i \in \mathcal{I} \text{ or some } d \in \mathcal{I}.$$

Notice that ε^* and ϕ^s are obtained as in Step 2. Now, however, (47) must also hold, which together with (59) implies we must have $\hat{T}(\varepsilon^*) = 0$, or equivalently, $\varepsilon^* = \hat{\varepsilon}$. In other words, this condition requires $R(\hat{\varepsilon}) = \hat{T}(\hat{\varepsilon})$, 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 $\bar{\phi}^s$, ϕ_t^m , 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, ε^* , characterized in Proposition 2 is strictly decreasing in the rate of inflation, i.e., $\frac{\partial \varepsilon^*}{\partial \mu} < 0$ 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

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

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),

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

and from (19), $\partial \phi^s / \partial \mu = \bar{\beta} \partial \phi^s / \partial \mu < 0$. (ii) Condition (14) implies $\partial \bar{\phi}^s / \partial \mu = \partial \varepsilon^* / \partial \mu + \partial \phi^s / \partial \mu < 0$. (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), $\partial \phi_t^m / \partial \mu = (y_t / A_t^m) \partial Z / \partial \mu < 0$. ■

Proof of Proposition 4. From condition (18),

$$\frac{\partial \varepsilon^*}{\partial(\alpha\theta)} = \frac{\frac{\mu - \bar{\beta}}{\alpha\theta} [\varepsilon^* + \bar{\beta}\delta(\bar{\varepsilon} - \varepsilon^*) \mathbb{I}_{\{\hat{\mu} < \mu\}}]}{\bar{\beta}\alpha\theta(1 - \bar{\beta}\delta)[1 - G(\varepsilon^*)] + (\mu - \bar{\beta}) \{1 + \bar{\beta}\delta[\alpha\theta G(\varepsilon^*) - 1] \mathbb{I}_{\{\hat{\mu} < \mu\}}\}} > 0. \quad (62)$$

(i) From (13),

$$\frac{\partial \phi^s}{\partial(\alpha\theta)} = \begin{cases} \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \frac{\partial \varepsilon^*}{\partial(\alpha\theta)} > 0 & \text{if } \bar{\beta} < \mu \leq \hat{\mu} \\ \frac{\bar{\beta}\delta}{1 - \bar{\beta}\delta} \left[\int_{\varepsilon_L}^{\varepsilon^*} G(\varepsilon) d\varepsilon + \alpha\theta G(\varepsilon^*) \frac{\partial \varepsilon^*}{\partial(\alpha\theta)} \right] > 0 & \text{if } \hat{\mu} < \mu < \bar{\mu}. \end{cases}$$

(ii) From (14), $\partial \bar{\phi}^s / \partial(\alpha\theta) = \partial \varepsilon^* / \partial(\alpha\theta) + \partial \phi^s / \partial(\alpha\theta) > 0$. (iii) For $\mu \in (\hat{\mu}, \bar{\mu})$, (17) implies $\partial Z / \partial \alpha = (\partial Z / \partial \varepsilon^*) (\partial \varepsilon^* / \partial \alpha) > 0$ and therefore $\partial \phi_t^m / \partial \alpha = (\partial Z / \partial \alpha) (y_t / A_t^m) > 0$. ■

Proof of Proposition 5. (i) The result is immediate from the expression for A_D^s in Proposition 2. (ii) From (10) and (11),

$$\frac{\partial \hat{\mu}}{\partial(\alpha\theta)} = \bar{\beta}(1 - \bar{\beta}\delta) \left\{ \frac{(1 - \alpha\theta) \bar{\varepsilon}}{[1 - \alpha\theta G(\bar{\varepsilon})] \bar{\varepsilon}^2} \int_{\varepsilon_L}^{\bar{\varepsilon}} G(\varepsilon) d\varepsilon - \frac{\hat{\varepsilon} - \bar{\varepsilon}}{\hat{\varepsilon}} \right\}.$$

Notice that $\partial \hat{\mu} / \partial(\alpha\theta)$ approaches a positive value as $\alpha\theta \rightarrow 0$, and a negative value as $\alpha\theta \rightarrow 1$. Also, $\hat{\mu} \rightarrow \bar{\beta}$ both when $\alpha\theta \rightarrow 0$, and when $\alpha\theta \rightarrow 1$. Hence $\mu > \bar{\beta} = \lim_{\alpha\theta \rightarrow 0} \hat{\mu} = \lim_{\alpha\theta \rightarrow 1} \hat{\mu}$ 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 $\alpha\theta$, $A_D^s = 0$. In between those ranges there must exist values of $\alpha\theta$ such that $\mu < \hat{\mu}$ which implies $A_D^s > 0$. ■

Proof of Proposition 6. (i) Differentiate (20) to get

$$\frac{\partial \mathcal{V}}{\partial \mu} = 2\alpha G'(\varepsilon^*) (A^s - \delta \tilde{A}_D^s) \frac{\partial \varepsilon^*}{\partial \mu} < 0,$$

where the inequality follows from Corollary 3. Also, from (19), $\partial \mathcal{V} / \partial \iota = \bar{\beta} \partial \mathcal{V} / \partial \mu < 0$. (ii) From (20),

$$\begin{aligned} \frac{\partial \mathcal{V}}{\partial \theta} &= 2\alpha G'(\varepsilon^*) (A^s - \delta \tilde{A}_D^s) \frac{\partial \varepsilon^*}{\partial \theta} \\ \frac{\partial \mathcal{V}}{\partial \alpha} &= 2 \left[G(\varepsilon^*) + \alpha G'(\varepsilon^*) \frac{\partial \varepsilon^*}{\partial \alpha} \right] (A^s - \delta \tilde{A}_D^s) \end{aligned}$$

and both are positive since $\partial \varepsilon^* / \partial(\alpha\theta) > 0$ (see (62)). ■

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

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 Ξ . From (65), we know that the disturbances of the reduced-form VAR (64) are linear combinations of the structural shocks, ε_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 Ξ , (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.³⁴

³⁴The 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., $Y_t = (i_t, \mathcal{R}_t^I, \mathcal{T}_t^I)'$, where i_t , $\mathcal{R}_t^I$, and $\mathcal{T}_t^I$ are the measures of the policy rate, the stock return, and turnover described in Sections 6.1 and 6.2. Denote $\varepsilon_t = (\varepsilon_t^i, \varepsilon_t^{\mathcal{R}}, \varepsilon_t^{\mathcal{T}})'$, $u_t = (u_t^i, u_t^{\mathcal{R}}, u_t^{\mathcal{T}})'$, and

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

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

$$\begin{bmatrix} u_t^i \\ u_t^{\mathcal{R}} \\ u_t^{\mathcal{T}} \end{bmatrix} = \begin{bmatrix} k_i^i \\ k_{\mathcal{R}}^i \\ k_{\mathcal{T}}^i \end{bmatrix} \varepsilon_t^i + \begin{bmatrix} k_i^{\mathcal{R}} \\ k_{\mathcal{R}}^{\mathcal{R}} \\ k_{\mathcal{T}}^{\mathcal{R}} \end{bmatrix} \varepsilon_t^{\mathcal{R}} + \begin{bmatrix} k_i^{\mathcal{T}} \\ k_{\mathcal{R}}^{\mathcal{T}} \\ k_{\mathcal{T}}^{\mathcal{T}} \end{bmatrix} \varepsilon_t^{\mathcal{T}}. \quad (67)$$

Since we are only interested in the impulse responses for the monetary shock, ε_t^i , 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, $(\varepsilon_t^i, \varepsilon_t^{\mathcal{R}}, \varepsilon_t^{\mathcal{T}})$, are unobservable and some of the elements of K^{-1} are unknown (three elements are unknown in this 3×3 case). Suppose we had data on $\{\varepsilon_t^i\}$. Then we could run the regression $u_t^i = \kappa_i^i \varepsilon_t^i + \eta_t$ to estimate κ_i^i , where η_t is an error term. From (67) we have $\eta_t = k_i^{\mathcal{R}} \varepsilon_t^{\mathcal{R}} + k_i^{\mathcal{T}} \varepsilon_t^{\mathcal{T}}$, so $\mathbb{E}(\varepsilon_t^i \eta_t) = \mathbb{E}[\varepsilon_t^i (k_i^{\mathcal{R}} \varepsilon_t^{\mathcal{R}} + k_i^{\mathcal{T}} \varepsilon_t^{\mathcal{T}})] = 0$ (since we are assuming $\mathbb{E}(\varepsilon_t \varepsilon_t') = I$), and thus the estimate of κ_i^i could be used to identify k_i^i (up to a constant) via the population regression of u_t^i onto ε_t^i . Since ε_t^i is unobservable, one natural alternative is to find a proxy (instrumental) variable for it. Suppose there is a variable z_t such that

$$\mathbb{E}(z_t \varepsilon_t^{\mathcal{R}}) = \mathbb{E}(z_t \varepsilon_t^{\mathcal{T}}) = 0 < \mathbb{E}(z_t \varepsilon_t^i) \equiv v \text{ for all } t.$$

Then

$$\Lambda \equiv \mathbb{E}(z_t u_t) = K^{-1} \mathbb{E}(z_t \varepsilon_t) = (k_i^i, k_{\mathcal{R}}^i, k_{\mathcal{T}}^i)' v. \quad (68)$$

Since $\Lambda = (\Lambda_1, \Lambda_2, \Lambda_3)'$ is a known (3×1) vector, we can identify the coefficients of interest, $(k_i^i, k_{\mathcal{R}}^i, k_{\mathcal{T}}^i)$ up to the sign of the scalar v . To see this, notice (68) implies

$$v k_i^i = \Lambda_1 \quad (69)$$

$$v k_{\mathcal{R}}^i = \Lambda_2 \quad (70)$$

$$v k_{\mathcal{T}}^i = \Lambda_3 \quad (71)$$

with

$$v^2 = \mathbb{E}(z_t u_t)' \Xi^{-1} \mathbb{E}(z_t u_t). \quad (72)$$

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 $(k_i^i, k_{\mathcal{R}}^i, k_{\mathcal{T}}^i)$, i.e., combining (69) with (70), and (69) with (71), yields

$$\frac{k_{\mathcal{R}}^i}{k_i^i} = \frac{\Lambda_2}{\Lambda_1} \quad (73)$$

$$\frac{k_{\mathcal{T}}^i}{k_i^i} = \frac{\Lambda_3}{\Lambda_1}. \quad (74)$$

Thus $k_{\mathcal{R}}^i$ and $k_{\mathcal{T}}^i$ are identified. From (69), k_i^i is also identified but up to the sign of v .

Notice that if we run a two-stage least squares (2SLS) regression of $u_t^{\mathcal{R}}$ on u_t^i using z_t as instrument for u_t^i , then the estimate of the slope coefficient on this regression is Λ_2/Λ_1 . Similarly, Λ_3/Λ_1 corresponds to the instrumental variable estimate of the slope coefficient of a regression of $u_t^{\mathcal{T}}$ on u_t^i using z_t as an instrument for u_t^i .

In our application the unexpected changes in the nominal rate on FOMC policy announcement days is a natural instrument for the structural monetary policy shock, ε_t^i . That is, we restrict our sample to $t \in S_1$ and set $\{z_t\} = \{\Delta i_t\}$. 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 $\{u_t\}$.

Step 2: Run the regression $u_t^i = \kappa_0 + \kappa^i \Delta i_t + \eta_t$ on sample S_1 to obtain the OLS estimates of κ_0 and κ^i , namely $\hat{\kappa}_0$ and $\hat{\kappa}^i$, and construct the fitted values $\hat{u}_t^i = \hat{\kappa}_0 + \hat{\kappa}^i \Delta i_t$.

Step 3: Run the regressions $u_t^{\mathcal{R}} = \kappa_0 + \kappa^{\mathcal{R}} \hat{u}_t^i + \eta_t$ and $u_t^{\mathcal{T}} = \kappa_0 + \kappa^{\mathcal{T}} \hat{u}_t^i + \eta_t$ on sample S_1 to obtain the OLS estimates of $\kappa^{\mathcal{R}}$ and $\kappa^{\mathcal{T}}$, namely $\hat{\kappa}^{\mathcal{R}}$ and $\hat{\kappa}^{\mathcal{T}}$. Since $\hat{\kappa}^{\mathcal{R}} = \Lambda_2/\Lambda_1$ and $\hat{\kappa}^{\mathcal{T}} = \Lambda_3/\Lambda_1$, (73) and (74) imply $\hat{\kappa}^{\mathcal{R}} = k_{\mathcal{R}}^i/k_i^i$ and $\hat{\kappa}^{\mathcal{T}} = k_{\mathcal{T}}^i/k_i^i$.

For the purpose of getting impulse responses with respect to the shock ε_t^i , notice that the scale and sign of k_i^i are irrelevant, as they can be set by normalizing the shock ε_t^i to have any desired impact on a given variable.³⁵ For example, in our impulse responses we normalize the shock ε_t^i so that it induces a 1 pp increase in the level of the policy rate i_t on impact. To see

³⁵Alternatively, (69) and (72) can be combined to get $k_i^i = \Lambda_1/v$, which is then identified up to the sign of v .

this, consider (67) with $\varepsilon_t^{\mathcal{R}} = \varepsilon_t^{\mathcal{T}} = 0$. Then the shock that induces an x pp increase in the level of the policy rate on impact (e.g., at $t = 0$), is $\varepsilon_0^i = (x/100)/k_i^i = (x/100)/(\Lambda_1/v)$.

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 $Y_t^b = \hat{B}Y_{t-1} + e_t^b \hat{u}_t$, 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 Δi_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 criterion (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.³⁶
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.

B.2 Equilibrium conditions for the model with M states and N assets

Let the state of this economy be $\mathbf{x}_t = ((A_t^{ms})_{s \in \mathbb{N}}, A_t^m, y_t, \mu_t) \in \mathbb{R}_+^{N+3}$, where A_t^{ms} denotes the amount of money that investors have available to trade asset s at the beginning of period t .³⁷ The laws of motion for the state variables A_t^m , y_t , and μ_t are exogenous (as described above) while $A_{t+1}^{ms} = \Psi^{ms}(\mathbf{x}_t)$, where the function Ψ^{ms} is determined in equilibrium. Asset prices in the recursive equilibrium are time-invariant functions of the state, i.e., $\phi_t^s = \phi^s(\mathbf{x}_t)$, $\bar{\phi}_t^s = \bar{\phi}^s(\mathbf{x}_t)$, $\phi_t^m = \phi^m(\mathbf{x}_t)$, $p_t^s = p^s(\mathbf{x}_t)$, and $\varepsilon_t^{s*} = \varepsilon^{s*}(\mathbf{x}_t)$. Lemma 1 still characterizes the equilibrium post-trade portfolios of dealers and investors in the OTC market. The investor's

³⁶Measurement noise is added to the equilibrium path of the turnover rate as explained in footnote 32.

³⁷As it will become clear, the state can be reduced to $\mathbf{x}_t = (A_t^m, y_t, \mu_t)$ in the class of equilibria we consider.

value functions are

$$\begin{aligned}
W^I((a_t^{ms}, a_t^s)_{s \in \mathbb{N}}, -k_t; \mathbf{x}_t) &= \sum_{s \in \mathbb{N}} [\phi^m(\mathbf{x}_t) a_t^{ms} + \phi^s(\mathbf{x}_t) a_t^s] - k_t + \bar{W}^I(\mathbf{x}_t) \\
V^I((a_t^{ms}, a_t^s)_{s \in \mathbb{N}}, \varepsilon; \mathbf{x}_t) &= \sum_{s \in \mathbb{N}} \{ \phi^m(\mathbf{x}_t) a_t^{ms} + [\varepsilon y_t + \phi^s(\mathbf{x}_t)] a_t^s \} + \bar{W}^I(\mathbf{x}_t) \\
&\quad + \sum_{s \in \mathbb{N}} \left\{ \alpha^s \theta [\varepsilon - \varepsilon^{s*}(\mathbf{x}_t)] y_t \mathbb{I}_{\{\varepsilon^{s*}(\mathbf{x}_t) < \varepsilon\}} \frac{1}{p^s(\mathbf{x}_t)} a_t^{ms} \right. \\
&\quad \left. + \alpha^s \theta [\varepsilon^{s*}(\mathbf{x}_t) - \varepsilon] y_t \mathbb{I}_{\{\varepsilon < \varepsilon^{s*}(\mathbf{x}_t)\}} a_t^s \right\}
\end{aligned}$$

where

$$\begin{aligned}
\bar{W}^I(\mathbf{x}_t) &\equiv T(\mathbf{x}_t) + \max_{(\tilde{a}_{t+1}^{ms}, \tilde{a}_{t+1}^s)_{s \in \mathbb{N}} \in \mathbb{R}_+^{2N}} \left\{ - \sum_{s \in \mathbb{N}} [\phi^m(\mathbf{x}_t) \tilde{a}_{t+1}^{ms} + \phi^s(\mathbf{x}_t) \tilde{a}_{t+1}^s] \right. \\
&\quad \left. + \beta \mathbb{E} \left[\int V^I((\tilde{a}_{t+1}^{ms}, \tilde{a}_{t+1}^s)_{s \in \mathbb{N}}, \varepsilon; \mathbf{x}_{t+1}) dG(\varepsilon) \middle| \mathbf{x}_t \right] \right\}
\end{aligned}$$

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

Lemma 5 *Let $(\tilde{a}_{t+1}^{ms}, \tilde{a}_{t+1}^s)_{s \in \mathbb{N}}$ denote the portfolios chosen by an investor in the second subperiod of period t of a recursive equilibrium. These portfolios must satisfy the following first-order necessary and sufficient conditions:*

$$\phi^m(\mathbf{x}_t) \geq \beta \mathbb{E} \left[\phi^m(\mathbf{x}_{t+1}) + \alpha^s \theta \int_{\varepsilon^{s*}(\mathbf{x}_{t+1})}^{\varepsilon^H} [\varepsilon - \varepsilon^{s*}(\mathbf{x}_{t+1})] y_{t+1} dG(\varepsilon) \frac{1}{p^s(\mathbf{x}_{t+1})} \middle| \mathbf{x}_t \right] \quad (75)$$

$$\phi^s(\mathbf{x}_t) \geq \beta \delta \mathbb{E} \left[\bar{\varepsilon} y_{t+1} + \phi^s(\mathbf{x}_{t+1}) + \alpha^s \theta \int_{\varepsilon_L}^{\varepsilon^{s*}(\mathbf{x}_{t+1})} [\varepsilon^{s*}(\mathbf{x}_{t+1}) - \varepsilon] y_{t+1} dG(\varepsilon) \middle| \mathbf{x}_t \right] \quad (76)$$

where (75) holds with “=” if $\tilde{a}_{t+1}^{ms} > 0$ and (76) holds with “=” if $\tilde{a}_{t+1}^s > 0$.

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*

$$\{ \phi^m(\cdot), \{ \phi^s(\cdot), p^s(\cdot), \varepsilon^{s*}(\cdot), \Psi^{ms}(\cdot) \}_{s \in \mathbb{N}} \}$$

that satisfy

$$\begin{aligned}
\phi^m(\mathbf{x}_t) &\geq \beta \mathbb{E} \left[\phi^m(\mathbf{x}_{t+1}) + \alpha^s \theta \int_{\varepsilon^{s*}(\mathbf{x}_{t+1})}^{\varepsilon^H} [\varepsilon - \varepsilon^{s*}(\mathbf{x}_{t+1})] y_{t+1} dG(\varepsilon) \frac{1}{p^s(\mathbf{x}_{t+1})} \middle| \mathbf{x}_t \right] \\
\phi^s(\mathbf{x}_t) &= \beta \delta \mathbb{E} \left[\bar{\varepsilon} y_{t+1} + \phi^s(\mathbf{x}_{t+1}) + \alpha^s \theta \int_{\varepsilon_L}^{\varepsilon^{s*}(\mathbf{x}_{t+1})} [\varepsilon^{s*}(\mathbf{x}_{t+1}) - \varepsilon] y_{t+1} dG(\varepsilon) \middle| \mathbf{x}_t \right] \\
p^s(\mathbf{x}_t) &= \frac{[1 - G(\varepsilon^{s*}(\mathbf{x}_t))] A_t^{ms}}{G(\varepsilon^{s*}(\mathbf{x}_t)) A^s} \\
\varepsilon^{s*}(\mathbf{x}_t) &= \frac{p^s(\mathbf{x}_t) \phi^m(\mathbf{x}_t) - \phi^s(\mathbf{x}_t)}{y_t} \\
A_{t+1}^{ms} &= \Psi^{ms}(\mathbf{x}_t) \\
\sum_{s \in \mathbb{N}} A_{t+1}^{ms} &= A_{t+1}^m
\end{aligned}$$

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

We conjecture the recursive equilibrium has the property that real prices are linear functions of the aggregate dividend, i.e., suppose $\mathbf{x}_t = (A_t^m, y_t, \mu_i)$. Then

$$\phi^s(\mathbf{x}_t) = \phi_i^s y_t \quad (77)$$

$$\bar{\phi}^s(\mathbf{x}_t) \equiv p^s(\mathbf{x}_t) \phi^m(\mathbf{x}_t) = \bar{\phi}_i^s y_t \quad (78)$$

$$\phi^m(\mathbf{x}_t) A_t^m = Z_i y_t \quad (79)$$

$$\phi^m(\mathbf{x}_t) A_t^{ms} = Z_i^s y_t \quad (80)$$

$$\varepsilon^{s*}(\mathbf{x}_t) \equiv \frac{\bar{\phi}^s(\mathbf{x}_t) - \phi^s(\mathbf{x}_t)}{y_t} = \bar{\phi}_i^s - \phi_i^s \equiv \varepsilon_i^{s*} \quad (81)$$

and the equilibrium conditions reduce to (25)-(28). Once (25)-(28) have been solved for $\{\varepsilon_i^{s*}, \phi_i^s, Z_i^s, Z_i\}_{i \in \mathbb{M}, s \in \mathbb{N}}$, for any given $\mathbf{x}_t = (A_t^m, y_t, \mu_i)$, $\phi^s(\mathbf{x}_t)$ is obtained from (77), $\bar{\phi}^s(\mathbf{x}_t)$ from (78) (with $\bar{\phi}_i^s = \varepsilon_i^{s*} + \phi_i^s$), $\phi^m(\mathbf{x}_t)$ from (79), and A_t^{ms} from (80).

References

- [1] Ang, Andrew, Assaf A. Shtauber, and Paul C. Tetlock. "Asset Pricing in the Dark: The Cross Section of OTC Stocks." NBER Working Paper 19309, August 2013.
- [2] Asness, Clifford. "Stocks versus Bonds: Explaining the Equity Risk Premium." *Financial Analysts Journal* 56(2) (March/April 2000): 96-113.
- [3] Asness, Clifford. "Fight the Fed Model: The Relationship between Future Returns and Stock and Bond Market Yields." *Journal of Portfolio Management* 30(1) (Fall 2003): 11-24.
- [4] Barlevy, Gadi. "Economic Theory and Asset Bubbles." Federal Reserve Bank of Chicago *Economic Perspectives* 31(3) (Quarter 3 2007): 44-59.
- [5] Basak, Suleyman, and Hongjun Yan. "Equilibrium Asset Prices and Investor Behaviour in the Presence of Money Illusion." *Review of Economic Studies* 77(3) (July 2010): 914-936.
- [6] Bekaert, Geert, and Eric Engstrom. "Inflation and the Stock Market: Understanding the Fed Model." *Journal of Monetary Economics* 57(3) (April 2010): 278-294
- [7] Berentsen, Aleksander, Guillaume Rocheteau, and Shouyong Shi. "Friedman Meets Hosios: Efficiency in Search Models of Money." *Economic Journal* 117(516) (January 2007): 174-195.
- [8] Bernanke, Ben S., and Kenneth N. Kuttner. "What Explains the Stock Market's Reaction to Federal Reserve Policy?" *The Journal of Finance* 60(3) (June 2005) 1221-1257.
- [9] Bodie, Zvi. "Common Stocks as a Hedge Against Inflation." *Journal of Finance* 31(2) (May 1976): 459-470.
- [10] Bordo, Michael, and David C. Wheelock. "Stock Market Booms and Monetary Policy in the 20th Century." Federal Reserve Bank of St. Louis *Review* 89(2) (March/April 2007): 91-122.
- [11] Brunnermeier, Markus K. "bubbles." In *The New Palgrave Dictionary of Economics*, edited by S. Durlauf and L. Blume. Basingstoke: Palgrave Macmillan, 2008.

- [12] Brunnermeier, Markus K., and Christian Julliard. “Money Illusion and Housing Frenzies.” *Review of Financial Studies* 21(1) (January 2008): 135-180.
- [13] Cagan, Phillip. “Common Stock Values and Inflation—The Historical Record of Many Countries.” National Bureau of Economic Research Supplement to NBER Report Thirteen (March 1974): 1-10.
- [14] Campbell, John Y., and Tuomo Vuolteenaho. “Inflation Illusion and Stock Prices.” *American Economic Review* 94(2) (May 2004): 19-23.
- [15] Campbell, John Y., Carolin Pflueger, and Luis M. Viceira. “Monetary Policy Drivers of Bond and Equity Risks.” NBER Working Paper 20070, April 2014.
- [16] Cass, David, and Karl Shell. “Do Sunspots Matter?” *Journal of Political Economy* 91(2) (April 1983): 193-227.
- [17] Cochrane, John, and Monika Piazzesi. “The Fed and Interest Rates: A High-Frequency Identification.” *American Economic Review P&P* 92(2) (May 2002): 90-95.
- [18] Cohen, Randolph B., Christopher Polk, and Tuomo Vuolteenaho. “Money Illusion in the Stock Market: The Modigliani-Cohn Hypothesis.” *Quarterly Journal of Economics* 120(2) (May 2005): 639-668.
- [19] Cook, Timothy, and Thomas Hahn. “The Effect of Changes in the Federal Funds Rate Target on Market Interest Rates in the 1970s.” *Journal of Monetary Economics* 24(3) (November 1989): 331-351.
- [20] Duffie, Darrell, Nicolae Gârleanu, and Lasse Heje Pedersen. “Over-the-Counter Markets.” *Econometrica* 73(6) (November 2005): 1815-1847.
- [21] Fama, Eugene F., and G. William Schwert. “Asset Returns and Inflation.” *Journal of Financial Economics* 5(2) (November 1977): 115-146.
- [22] Feinman, Joshua N. “Inflation Illusion and the (Mis)Pricing of Assets and Liabilities.” *Journal of Investing* 14(2) (Summer 2005): 29-36.
- [23] Ferraris, Leo, and Makoto Watanabe. “Collateral Fluctuations in a Monetary Economy.” *Journal of Economic Theory* 146(5) (September 2011): 1915-1940.

- [24] Geromichalos, Athanasios, and Lucas Herrenbrueck. “Monetary Policy, Asset Prices, and Liquidity in Over-the-Counter Markets.” UC Davis, mimeo, 2012.
- [25] Geromichalos, Athanasios, Juan M. Licari and José Suárez-Lledo. “Asset Prices and Monetary Policy.” *Review of Economic Dynamics* 10(4) (October 2007): 761-779.
- [26] Gertler, Mark, and Peter Karadi. “Monetary Policy Surprises, Credit Costs, and Economic Activity.” *American Economic Journal: Macroeconomics* 7(1) (January 2015): 44-76.
- [27] Gordon, Myron J. *The Investment, Financing, and Valuation of the Corporation*. Irwin, Homewood, IL, 1962.
- [28] Gorodnichenko, Yuriy, and Michael Weber. “Are Sticky Prices Costly?: Evidence from the Stock Market.” Manuscript, 2015.
- [29] Gürkaynak, Refet S., Brian P. Sack, and Eric T. Swanson. “Market-Based Measures of Monetary Policy Expectations.” *Journal of Business and Economic Statistics* 25(2) (April 2007) 201-212.
- [30] Harrison, J. Michael, and David M. Kreps. “Speculative Investor Behavior in a Stock Market with Heterogeneous Expectations.” *Quarterly Journal of Economics* 92(2) (May 1978): 323-336.
- [31] He, Chao, Randall Wright, and Yu Zhu. “Housing and Liquidity.” University of Wisconsin, mimeo, 2012.
- [32] Hosios, Arthur J. “On the Efficiency of Matching and Related Models of Search and Unemployment.” *Review of Economic Studies* 57(2) (April 1990): 279-298.
- [33] Jacquet, Nicolas L. and Serene Tan. “Money and Asset Prices with Uninsurable Risks.” *Journal of Monetary Economics* 59(8) (December 2012): 784-797.
- [34] Jaffe, Jeffrey and Gershon Mandelker. “The ‘Fisher Effect’ for Risky Assets: An Empirical Investigation.” *Journal of Finance* 31(2) (May 1976): 447-458.
- [35] Jensen, Gerald R., Jeffrey M. Mercer, and R. R. Johnson. “Business Conditions, Monetary Policy, and Expected Security Returns.” *Journal of Financial Economics* 40(2) (February 1996): 213-237.

- [36] Kuttner, Kenneth N. “Monetary Policy Surprises and Interest Rates: Evidence From the Fed Funds Futures Market.” *Journal of Monetary Economics* 47(3) (June 2001): 523-544.
- [37] Lagos, Ricardo. “Some Results on the Optimality and Implementation of the Friedman Rule in the Search Theory of Money.” *Journal of Economic Theory* 145(4) (July 2010): 1508-1524.
- [38] Lagos, Ricardo. “Asset Prices and Liquidity in an Exchange Economy.” *Journal of Monetary Economics* 57(8) (November 2010): 913-930.
- [39] Lagos, Ricardo. “Asset Prices, Liquidity, and Monetary Policy in an Exchange Economy.” *Journal of Money, Credit and Banking* 43(7) (October 2011): 521-552.
- [40] Lagos, Ricardo, and Guillaume Rocheteau. “Money and Capital as Competing Media of Exchange.” *Journal of Economic Theory* 142(1) (September 2008): 247-258.
- [41] Lagos, Ricardo, and Guillaume Rocheteau. “Liquidity in Asset Markets with Search Frictions.” *Econometrica* 77(2) (March 2009): 403-426.
- [42] Lagos, Ricardo, Guillaume Rocheteau, and Pierre-Olivier Weill. “Crises and Liquidity in Over-the-Counter Markets.” *Journal of Economic Theory* 146(6) (November 2011): 2169-2205.
- [43] Lagos, Ricardo, and Randall Wright. “Dynamics, Cycles and Sunspot Equilibria in ‘Genuinely Dynamic, Fundamentally Disaggregative’ Models of Money.” *Journal of Economic Theory* 109(2) (April 2003): 156-171.
- [44] Lagos, Ricardo, and Randall Wright. “A Unified Framework for Monetary Theory and Policy Analysis.” *Journal of Political Economy* 113(3) (June 2005): 463-484.
- [45] Lagos, Ricardo, and Shengxing Zhang. “Monetary Exchange in Over-the-Counter Markets: A Theory of Speculative Bubbles, the Fed Model, and Self-Fulfilling Liquidity Crises.” NBER Working Paper 21528, September 2015.
- [46] Lansing, Kevin J. “Inflation-Induced Valuation Errors in the Stock Market.” Federal Reserve Bank of San Francisco *Economic Letter* 30 (November 2004): 1-3.

- [47] Lester, Benjamin, Andrew Postlewaite, and Randall Wright. “Information, Liquidity, Asset Prices, and Monetary Policy.” *Review of Economic Studies* 79 (3) (July 2012): 1208-1238.
- [48] Lettau, Martin, and Sydney C. Ludvigson. “Expected Returns and Expected Dividend Growth.” *Journal of Financial Economics* 76(3) (June 2005): 583-626.
- [49] Li, Ying-Syuan, and Yiting Li. “Liquidity, Asset Prices, and Credit Constraints.” National Taiwan University, mimeo, 2012.
- [50] Lintner, John. “Inflation and Security Returns.” Papers and Proceedings of the Thirty-Third Annual Meeting of the American Finance Association, San Francisco, California, December 28-30, 1974. *Journal of Finance* 30(2) (May 1975): 259-280.
- [51] Lucas, Robert E., Jr. “Asset Prices in an Exchange Economy.” *Econometrica* 46(6) (November 1978): 1426-1445.
- [52] Mertens, Karel, and Morten O. Ravn. “The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States.” *American Economic Review* 103(4) (June 2013): 1212-47.
- [53] Modigliani, Franco, and Richard A. Cohn. “Inflation, Rational Valuation and the Market.” *Financial Analysts Journal* (March/April 1979): 24-44.
- [54] Nakamura, Emi, and Jón Steinsson. “High-Frequency Identification of Monetary Non-Neutrality.” Manuscript, 2015.
- [55] Nelson, Charles R. “Inflation and Rates of Return on Common Stocks.” *Journal of Finance* 31(2) (May 1976): 471-483.
- [56] Nosal, Ed, and Guillaume Rocheteau. “Pairwise Trades, Asset Prices, and Monetary Policy.” *Journal of Economic Dynamics and Control* 37(1) (January 2013): 1-17.
- [57] Ritter, Jay R., and Richard S. Warr. “The Decline of Inflation and the Bull Market of 1982—1999.” *Journal of Financial and Quantitative Analysis* 37(1) (March 2002): 29-61.
- [58] Rigobon, Roberto, and Brian Sack. “The Impact of Monetary Policy on Asset Prices.” *Journal of Monetary Economics* 51(8) (November 2004): 1553-1575.

- [59] Rocheteau, Guillaume, and Randall Wright. "Liquidity and Asset-Market Dynamics." *Journal of Monetary Economics* 60(2) (March 2013): 275-294.
- [60] Scheinkman, José A. "Speculation, Trading and Bubbles." Princeton University Economic Theory Center, Research Paper No. 050-2013 (April 2013).
- [61] Scheinkman, José A., and Wei Xiong. "Heterogeneous Beliefs, Speculation and Trading in Financial Markets." *Lectures in Mathematics*, Paris-Princeton Lectures in Mathematical Finance 2003, edited by Tomasz R. Bielecki, Tomas Björk, Monique Jeanblanc, Marek Rutkowski, José A. Scheinkman, and Wei Xiong, Springer, 2003.
- [62] Scheinkman, José A., and Wei Xiong. "Overconfidence and Speculative Bubbles." *Journal of Political Economy* 111(6) (December 2003): 1183-1219.
- [63] Schneider, Martin, and Monika Piazzesi. "Inflation Illusion, Credit, and Asset Prices." In *Asset Prices and Monetary Policy* edited by John Y. Campbell. University of Chicago Press, 2008.
- [64] Sharpe, Steven A. "Reexamining Stock Valuation and Inflation: The Implications of Analysts' Earnings Forecasts." *Review of Economics and Statistics* 84(4) (November 2002), 632-648.
- [65] Shi, Shouyong. "Money and Prices: A Model of Search and Bargaining." *Journal of Economic Theory* (67) 2 (December 1995): 467-496.
- [66] Siegel, Jeremy J. "The Rise in Stock Valuations and Future Equity Returns." *Journal of Investment Consulting* (Summer 2002).
- [67] Stock, James H., and Mark W. Watson. "Disentangling the Channels of the 2007-2009 Recession." NBER Working Paper 18094, May 2012.
- [68] Thorbecke, Willem. "On Stock Market Returns and Monetary Policy." *The Journal of Finance* 52(2) (June 1997): 635-654.
- [69] Trejos, Alberto, and Randall Wright. "Search, Bargaining, Money, and Prices." *Journal of Political Economy* 103(1) (February 1995): 118-141.

- [70] Trejos, Alberto, and Randall Wright. “Money and Finance: An Integrated Approach.” University of Wisconsin, mimeo, 2012.
- [71] Williams, John Burr. *The Theory of Investment Value*. Harvard University Press, Cambridge, MA, 1938.
- [72] Xiong, Wei. “Bubbles, Crises and Heterogeneous Beliefs.” NBER working paper 18905, March 2013.
- [73] Zhang, Shengxing. “Liquidity Misallocation in an Over-The-Counter Market.” NYU mimeo, 2012.

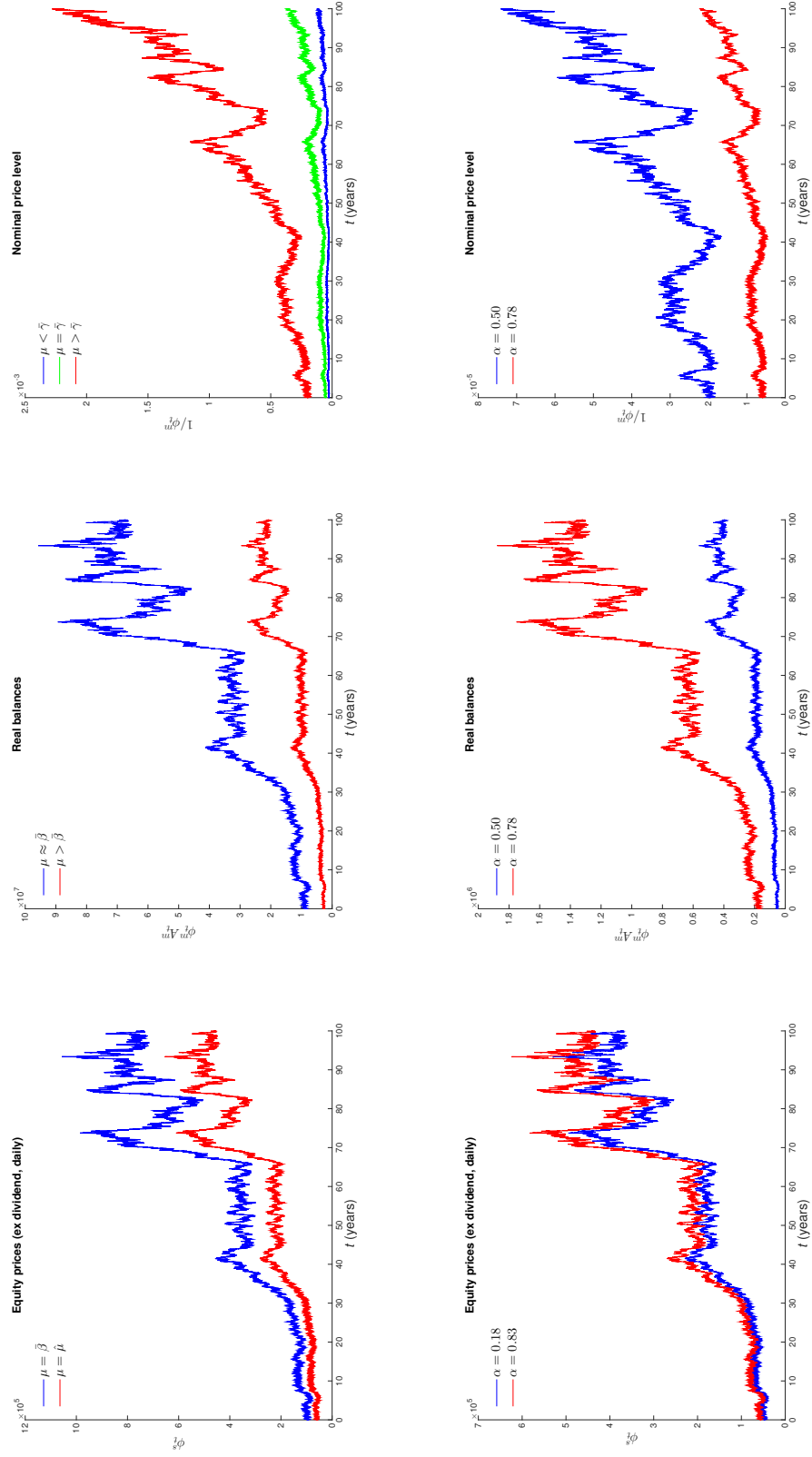


Figure 1: Effects of monetary policy and OTC frictions on asset prices

	E-study		H-based	
	Estimate	Std dev	Estimate	Std dev
Return	-3.77	1.02	-6.18	1.87
Turnover	-.0025	.0007	-.0045	.0017

Table 1: Empirical response of stock returns and turnover to monetary policy. All estimates are significant at 1% level.

Portfolio	E-based						H-based					
	Return			Turnover			Return			Turnover		
	Estimate	Std dev	Estimate	Estimate	Std dev	Std dev	Estimate	Std dev	Estimate	Estimate	Std dev	Std dev
1	-2.03	.73	-3.31e-04	-3.31e-04	2.52e-04	1.12	-3.40	1.12	-8.11e-04	-8.11e-04	5.41e-04	5.41e-04
2	-1.83	.85	-7.63e-04	-7.63e-04	3.80e-04	1.45	-3.77	1.45	-.0014	-.0014	6.31e-04	6.31e-04
3	-1.57	.91	-7.06e-04	-7.06e-04	5.28e-04	1.78	-3.02	1.78	-.0012	-.0012	6.65e-04	6.65e-04
4	-1.05	.87	2.12e-04	2.12e-04	6.73e-04	1.84	-2.69	1.84	4.78e-04	4.78e-04	.0011	.0011
5	-2.54	1.03	-.0011	-.0011	5.43e-04	2.43	-5.21	2.43	-.0020	-.0020	8.88e-04	8.88e-04
6	-2.67	1.01	-.0021	-.0021	9.18e-04	1.81	-4.58	1.81	-.0039	-.0039	.0013	.0013
7	-3.33	1.06	-.0016	-.0016	6.63e-04	2.80	-6.11	2.80	-.0031	-.0031	.0011	.0011
8	-2.55	1.12	-.0011	-.0011	6.92e-04	2.12	-4.81	2.12	-.0024	-.0024	.0012	.0012
9	-2.65	1.20	-.0023	-.0023	7.89e-04	2.45	-5.00	2.45	-.0034	-.0034	.0016	.0016
10	-4.33	1.19	-.0027	-.0027	9.05e-04	2.50	-7.25	2.50	-.0065	-.0065	.0030	.0030
11	-3.88	1.22	-.0023	-.0023	8.69e-04	2.33	-6.20	2.33	-.0039	-.0039	.0014	.0014
12	-3.76	1.26	-.0030	-.0030	9.58e-04	2.30	-5.98	2.30	-.0059	-.0059	.0020	.0020
13	-3.98	1.15	-.0028	-.0028	.0015	2.40	-6.62	2.40	-.0050	-.0050	.0019	.0019
14	-4.73	1.31	-.0034	-.0034	.0011	2.43	-7.71	2.43	-.0061	-.0061	.0025	.0025
15	-4.69	1.30	-.0035	-.0035	.0014	2.50	-7.61	2.50	-.0068	-.0068	.0027	.0027
16	-5.37	1.56	-.0037	-.0037	.0012	2.92	-9.10	2.92	-.0066	-.0066	.0028	.0028
17	-6.02	1.44	-.0078	-.0078	.0019	3.20	-10.50	3.20	-.0136	-.0136	.0044	.0044
18	-5.21	1.67	-1.30e-04	-1.30e-04	2.57e-04	3.01	-8.82	3.01	-1.02e-04	-1.02e-04	2.19e-04	2.19e-04
19	-5.93	1.81	-.0083	-.0083	.0021	3.62	-10.57	3.62	-.0153	-.0153	.0050	.0050
20	-6.27	2.09	-.0088	-.0088	.0030	4.10	-12.01	4.10	-.0172	-.0172	.0078	.0078

Table 2: Empirical responses of stock returns and turnover to monetary policy across NYSE liquidity portfolios.

Variable	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)
Δi_t	-2.52 (.086)	-2.40 (.090)	-2.46 (.091)	-2.37 (.097)	-2.44 (.098)	-3.36 (.099)	-3.37 (.100)	-3.62 (.110)	-3.63 (.110)
$\mathcal{T}_t^s$	25.93 (2.26)	25.36 (2.26)	17.54 (3.08)	22.37 (2.29)	13.93 (3.16)	45.29 (5.71)	42.58 (7.55)	39.09 (5.72)	33.13 (7.71)
$\overline{\mathcal{T}_t^s} \times \overline{\Delta i_t}$		-109.43 (25.36)	-121.14 (25.76)	-100.43 (25.28)	-111.09 (25.68)	-403.98 (28.22)	-415.17 (28.71)	-398.96 (28.06)	-410.15 (28.55)
D_s			yes		yes		yes		yes
D_t				yes	yes			yes	yes
$(\Delta i_t)^2$						.947 (.041)	.947 (.042)	1.00 (.042)	1.00 (.043)
$(\mathcal{T}_t^s)^2$						-1696.88 (392.48)	-1921.29 (465.31)	-1378.21 (389.33)	-1418.23 (466.21)
R^2	.0084	.0086	.0085	.0314	.0316	.0132	.0132	.0363	.0364

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.

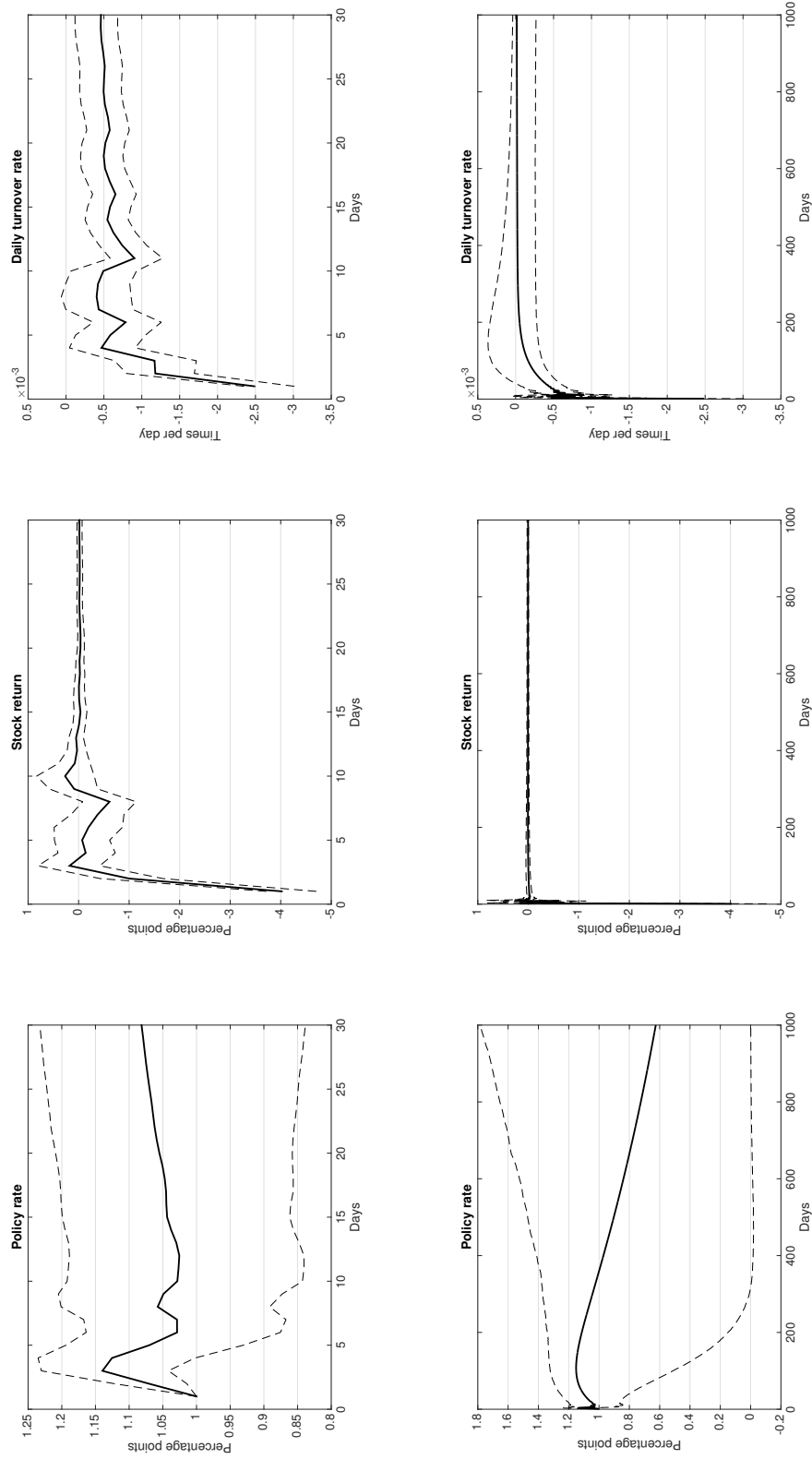


Figure 2: Empirical impulse responses to a 1 percentage point increase in the policy rate. Solid lines are point estimates. Broken lines are 95 percent confidence intervals

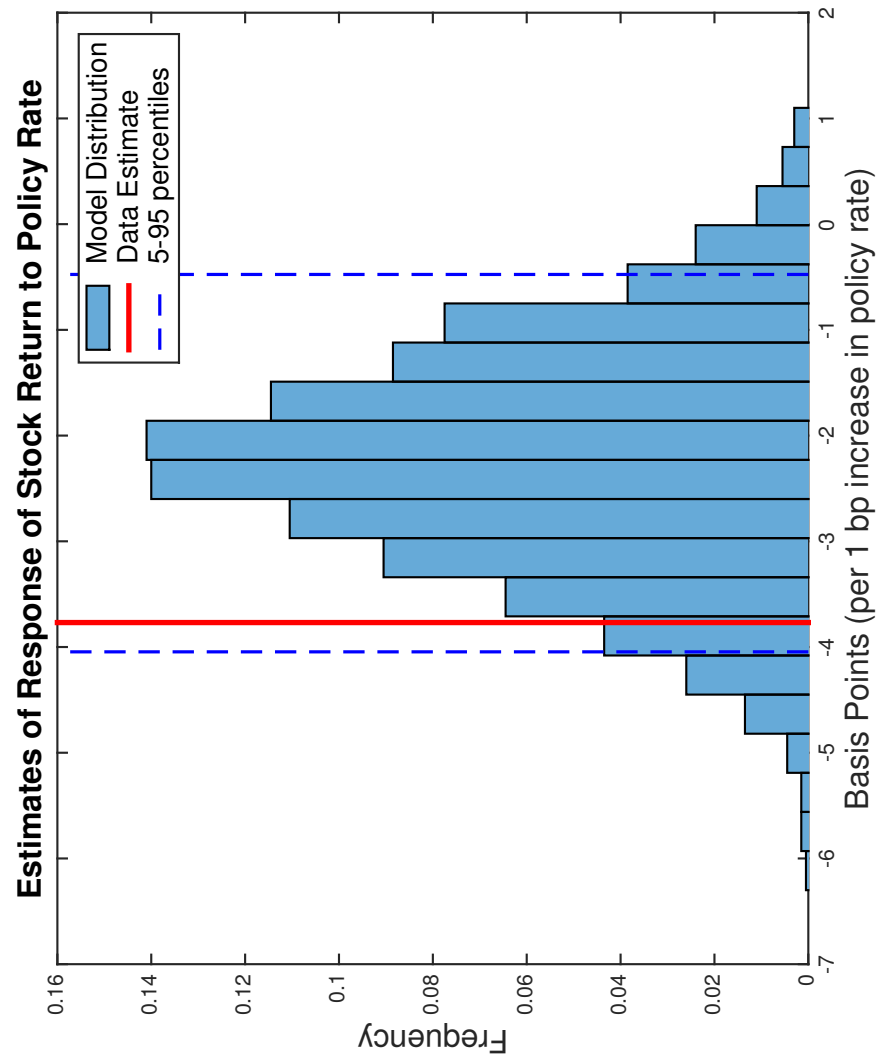


Figure 3: Estimates of announcement-day response of stock return to policy rate

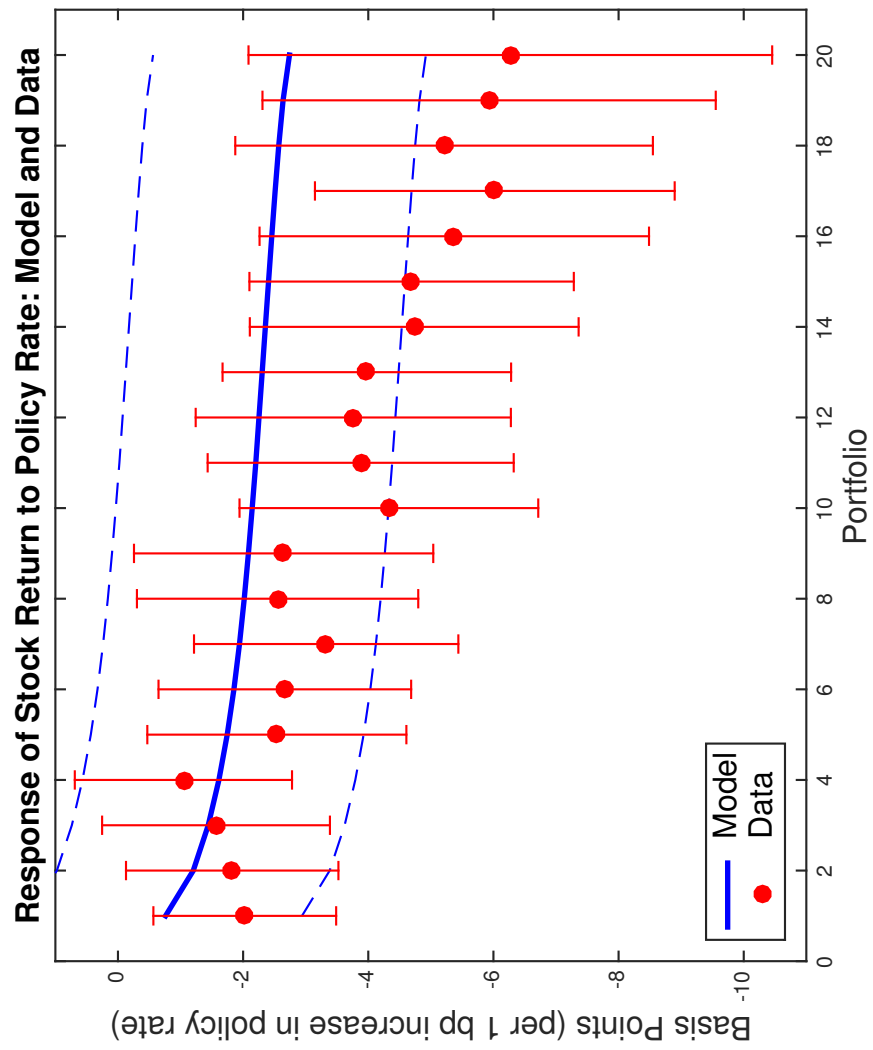


Figure 4: Cross-sectional announcement-day responses of stock returns to policy rate

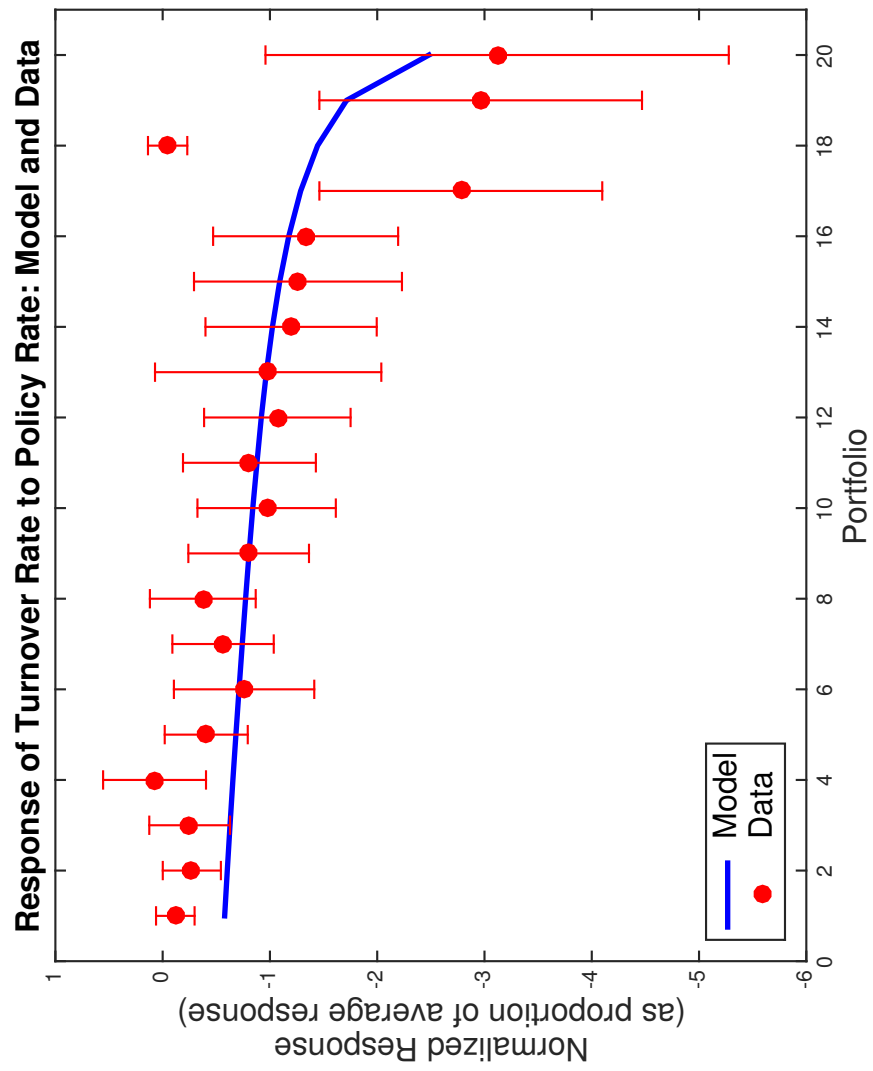


Figure 5: Cross-sectional announcement-day normalized responses of turnover rates to policy rate

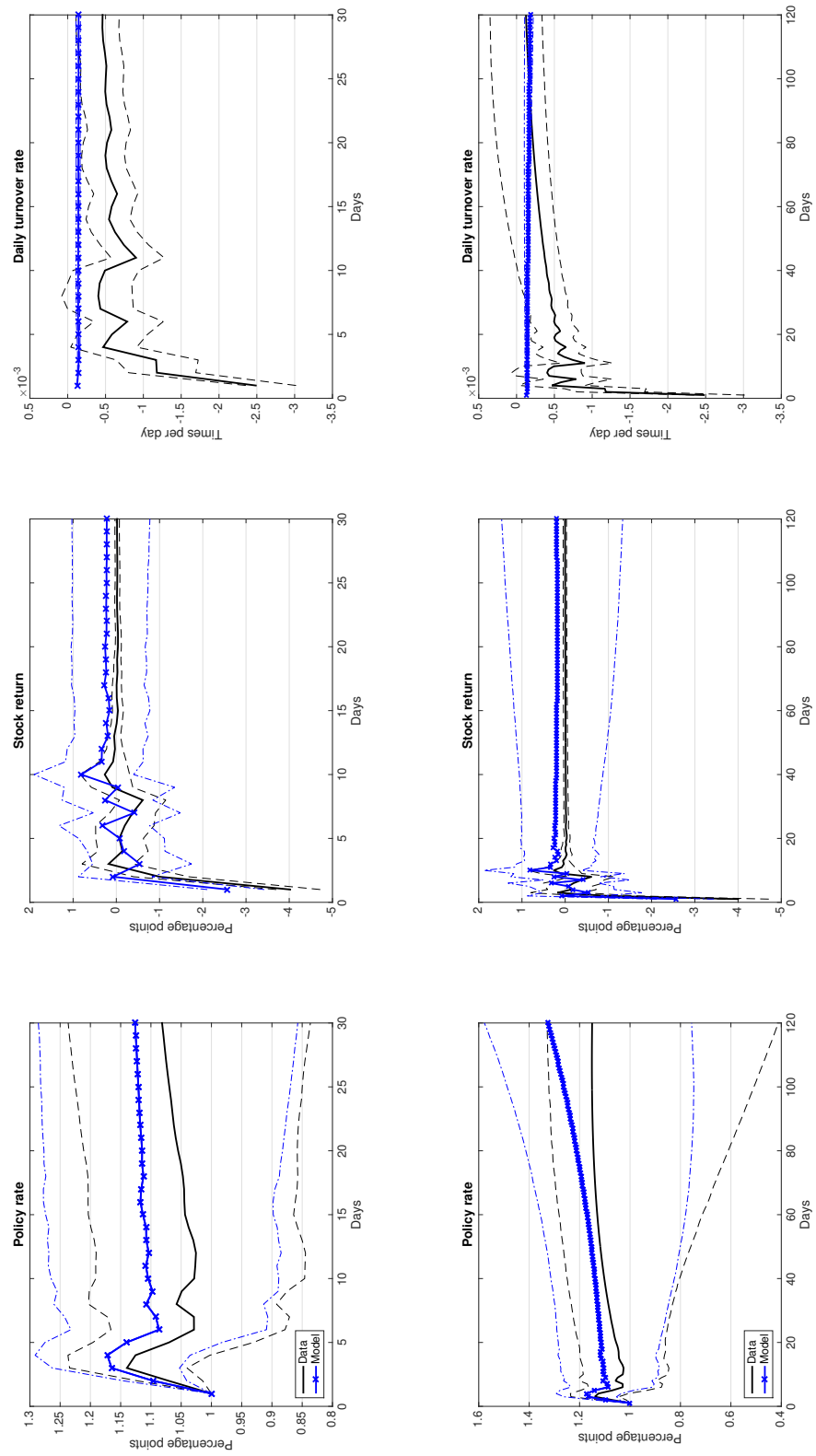


Figure 6: Impulse responses to a 1 percentage point increase in the policy rate. Solid lines are point estimates. Broken lines are 95 percent confidence intervals

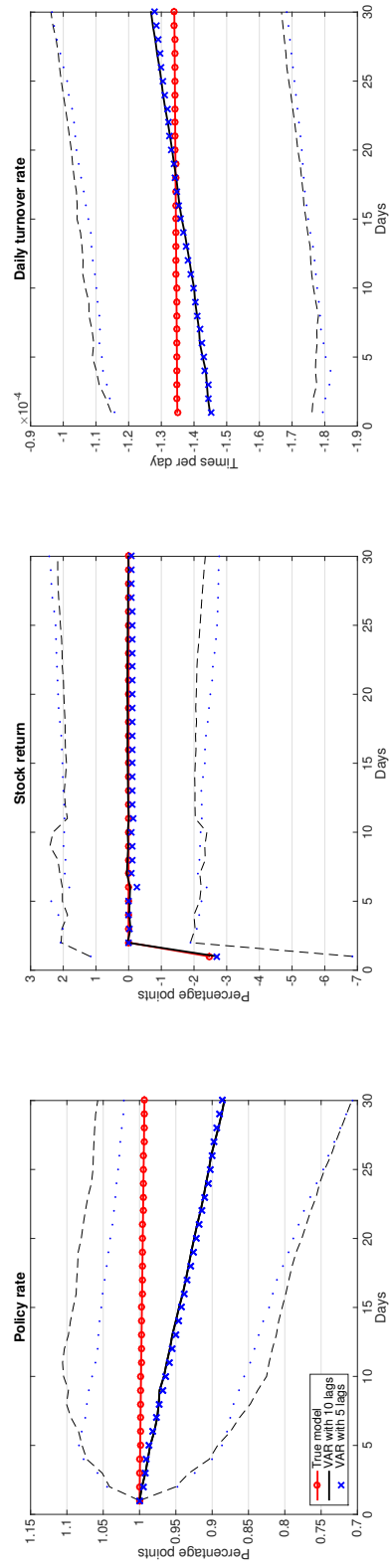


Figure 7: Model-based impulse responses to a 1 percentage point increase in the policy rate. Solid lines are point estimates. Broken lines are 95 percent confidence intervals