

An Empirical Analysis of Strategic Games in the Tri-Party Repo Market
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ABSTRACT

This paper discusses the strategies of clearing banks, securities dealers, and cash investors in the tri-party repo market using game theory and multiple regression analysis. Data from the Federal Reserve Bank of New York, Bank of New York Mellon, and the Bureau of Economic Analysis were recorded on a quarterly basis after the Primary Dealer Credit Facility's closure, from February 2010 through September 2014. Empirical results indicate that real Gross Domestic Product and the collateral value of agency mortgage-backed securities for repos significantly influence tri-party repo activity. These factors can motivate players' strategies, which partly determines the size of the tri-party repo market and supports game theoretic insights about this market's sensitivity to strategic and external uncertainty.

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1 Introduction

The tri-party repo market nearly collapsed during the 2008 financial crisis due to behavioral shifts of clearing banks and cash investors because of panic over potentially illiquid securities dealers. Perception of potential dealer illiquidity caused reputation risk and exacerbated counterparty risk. Huberto M. Ennis modeled these behavioral interactions using game theory to show how market participants make strategic decisions when counterparty liquidity information is limited. The purpose of this paper is to reexamine previous evidence as well as provide further results about the role of endogenous and exogenous factors that affect the tri-party repo market. The empirical results of this research support the previous conclusion that players in the tri-party repo market are sensitive to information. A detailed discussion of Ennis's game theoretic models is outlined by the events that led to the collapse of Lehman Brothers in relation to the role of mortgage-backed securities (MBS).

Does perception of dealer and investor liquidity, monetary policy, expectations about economic growth, and the value of agency MBS tri-party repo collateral affect tri-party repo activity? Three separate models use the Chicago Board Options Exchange Volatility Index (VIX), three-month U.S. treasury yield, real Gross Domestic Product (GDP), and various MBS variables to estimate Bank of New York Mellon's share of worldwide tri-party repo balances. Multiple linear regression analysis evaluates and compares the impact of those factors on actual market conditions with game theoretic modeling of the tri-party repo market presented in *Strategic Behavior in the Tri-Party Repo Market* (Ennis).

2 Literature Review

2.1 Historical Background

“Over a six month period from March [through] September of 2008, all five of the largest, free-standing investment banks [Goldman Sachs, JPMorgan Chase & Co., Merrill Lynch, Lehman Brothers Holdings, Inc., and The Bear Stearns Companies Inc.] ceased to exist in their old form”.¹ The alteration of these financial institutions was a corollary of the U.S. housing market collapse.

During the early 1990s, lax lending standards sprung up allowing unqualified borrowers to receive residential real estate loans securitized by agency MBS that were also used as collateral for tri-party repos. One example of relaxed standards took shape in 1992 when Congress enacted the Federal Housing Enterprises Safety and Soundness Act. This Act had a “key element that would, more than any other act, lead to disastrous home lending practices of the 2000s … [the Act] actually encouraged unsafe and unsound activities at both Fannie and Freddie by assigning them a new affordable housing mission”.² The Act eased payment standards by encouraging “Fannie and Freddie to buy mortgages where borrowers put down a nominal amount of 5 percent or less of the total amount”,³ while traditional banks normally required borrowers to put down 20 percent of the property price to secure a mortgage loan. These precipitating factors facilitated a housing bubble that gained strength over nearly two decades.

According to the S&P/Case-Shiller Home Price Index,ⁱⁱ domestic home prices peaked in July 2006 followed by a steep decline, which ended in February 2012.⁴ During the third quarter of 2006, delinquency rates on residential real estate loans ticked up to 1.75 percent from 1.62

ⁱⁱ “The S&P/Case-Shiller Home Price Indices are calculated monthly using a three-month moving average. Index levels are published with a two-month lag and are released at 9 am EST on the last Tuesday of every month. Index performance is based on non-seasonally adjusted data” (S&P Dow Jones Indices LLC).

percent in the previous quarter. As home prices declined, many borrowers defaulted on their real estate loans due to higher monthly payments on various different types of balloon loansⁱⁱⁱ and residential mortgages. Delinquency rates continuously rose until their peak of 11.27 percent during the first quarter of 2010. Many of these loans were packaged into agency MBS used to collateralize tri-party repo transactions. Climbing delinquency rates and falling home prices crippled the domestic housing market and nearly stunted funding in the tri-party repo market, given its exposure to agency MBS:

In the first quarter of 2010, 77 percent of Tri-party deals were financed by Treasury securities that included 27 percent treasuries, 37 percent agency mortgage-backed securities, and 13 percent fixed-income securities ... [concurrently] securities financed in the repo market totaled \$1.7 trillion, down from the peak of \$2.8 trillion in May 2008.⁵

The Federal Housing Enterprises Safety and Soundness Act encouraged Fannie Mae, Freddie Mac, and Ginnie Mae^{iv} to issue agency securities.⁶

All five of the largest investment banks, that existed during the financial crisis, as well as Fannie Mae and Freddie Mac have faced legal penalties over misconduct involving mortgage securities. The Securities and Exchange Commission (SEC) brought charges against Goldman Sachs for “defrauding investors by misstating and omitting key facts about a financial product tied to subprime mortgages as the U.S. housing market was beginning to falter (April 16, 2010). [The firm] agreed to pay record penalty in a \$550 million settlement and reform its business practices (July 15, 2010).”⁷ The SEC also charged JPMorgan Securities with “misleading investors in a complex mortgage securities transaction just as the housing market was starting to plummet. JPMorgan agreed to pay \$153.6 million in a settlement that enables harmed investors to receive all of their money back (June 21, 2011).”⁸ The SEC then “charged six former top

ⁱⁱⁱ “A balloon loan is a mortgage that requires a larger-than-usual one-time payment at the end of the term” (Consumer Financial Protection Bureau).

^{iv} Fannie Mae, Freddie Mac, and Ginnie Mae are all part of the Federal Home Loan Mortgage Corporation.

executives of Fannie Mae and Freddie Mac with securities fraud for misleading investors about the extent of each company's holdings of higher-risk mortgage loans, including subprime loans (December 16, 2011).⁹ Thereafter, on May 7, 2012, the United States District Court, Southern District of New York approved orders for final settlement in which Merrill Lynch was to pay “\$315 million to resolve claims against all defendants”.¹⁰ At the time, it was “the largest settlement of a class action asserting Securities Act claims related to the issuance of mortgage-backed securities.”¹¹ Subsequently, at the same Court on June 22, 2012, Judge Lewis A. Kaplan “approved a \$40 million settlement in a mortgage-backed securities class action lawsuit against individuals previously affiliated with Lehman Brothers Holding, Inc.”¹² On January 9, 2015 JPMorgan agreed, “to settle a lingering class action suit the bank giant inherited with its 2008 acquisition of Bear Stearns. Reuters reports that the bank will pay approximate \$500 million to a collection of pension funds that had been invested in the MBS at the time of the collapse.”¹³ Due to the role of MBS in the financial crisis, this study will regress various MBS variables against tri-party repo balances to determine if information about these securities can influence tri-party repo market participants’ strategic decisions.

2.2 The Repurchase Agreement

A repurchase agreement (referred to as ‘repo’) is a financial contract that outlines the details of a collateralized loan between two parties, such as financial securities dealers and cash investors. “Repos are especially important for allowing arbitrage in the Treasury, agency, and agency mortgage-backed securities markets, thus enhancing price discovery and market liquidity.¹⁴ Figure 1 illustrates the opening and closing legs of a repo transaction.

Figure 1 Repurchase Agreement¹⁵

Opening Leg



Closing Leg



A cash provider ('lender' or 'investor') lends cash to a collateral provider ('dealer' or 'borrower') in exchange for securities, which the dealer promises to repurchase at a future date, also known as the expiration or maturity date. Over the repo's term, the dealer pays an interest rate premium to the lender. When the repo either terminates or matures, the dealer buys back equivalent assets of the same type and class rather than the exact securities originally sold. The lender maintains ownership over the collateral, so these securities can be sold at any point over the repo's term. Therefore, the lender must return the same asset type and class of securities on the closing leg of a repo. This resale right offsets the credit risk that the lender is exposed to in the event that the dealer defaults.¹⁶ At any point throughout the repo's term, the lender has the right to resell the pledged securities on the open market. Credit risk protection provided by this resale right and the interest rate premium induces buyers to participate in the market.

2.3 Haircuts on Repos

A haircut is the difference between the amount of cash borrowed and the collateral value of the securities provided.^v Gorton and Metrick argue that the size of a haircut represents the perceived underlying risk of the collateral.¹⁷ Larger haircuts are often associated with higher risk securities while smaller haircuts usually indicate lower risk ones. Although haircuts do not ensure that, the original pledged securities will be returned to the dealer, they do provide a level of protection if the dealer fails before the expiration date.

2.4 Bilateral Repo Market

All repos were originally set up as bilateral transactions. Bilateral repos are settled when the dealer receives cash and delivers securities to the lender. Both parties instruct their custodian banks to deliver the securities and cash to their counterparty's accounts. These transactions are usually simultaneous and referred to as "delivery versus payment".¹⁸ The cash provider is responsible for keeping records of all incoming collateral, verifying the adequacy and market value of collateral, and ensuring that the proper haircut has been applied. Haircuts incentivize repos because they provide the cash provider with protection, in the form of interest, if the dealer fails to repay the loan throughout the life of the repo. Therefore, market participants require a necessary skillset to successfully execute bilateral repo transactions.

2.5 Tri-party Repo Market

^v "For example, if \$90 million is deposited and \$100 million of bonds is received as collateral, then there is a 'haircut' or initial margin of 10 percent" (Gorton and Metrick 508). This 10 percent haircut grants leverage to the lender if the dealer defaults and acts as a monetary incentive for the lender to enter into a repo transaction.

A key distinction between the bilateral and tri-party repo market is the presence of a third party, a clearinghouse, which intermediates transactions and provides collateral management services for dealers and lenders. In the U.S., Bank of New York Mellon (BNYM) and JPMorgan Chase (JPMC) exclusively clear transactions in this market. Copeland, Duffie, and Martin outline the clearing process as follows:

The clearing banks settle the opening leg of a tri-party repo by transferring securities from the dealer's securities account to the cash investor's securities account, and by transferring cash from the investor's cash account to the dealer's cash account. Movements in the opposite direction occur on the closing leg of the repo.¹⁹

Dealers and lenders often have accounts at both banks where collateral and cash are held, to be transferred and monitored by the clearing bank. Clearing repo and securities lending transactions are recorded on 10-K and 10-Q reports "to the extent that they occur on the balance sheet."²⁰ To encourage transparency, the Federal Reserve (FED) Bank of New York began publishing monthly tri-party repo data in 2010, enabling the FED to understand more about the tri-party than the bilateral repo market.²¹

2.6 Settling Tri-party Repos: A Two Step Process^{vi}

Clearinghouses settle both opening and closing legs of repos daily for lenders and dealers. The opening leg of a repo takes place when lenders send cash to dealers while dealers issue securities to lenders in return. The closing leg of the transaction occurs at maturity when a lender returns securities of the same asset class and type that were originally pledged, and the dealer repays the loan plus interest.

Each morning banks 'unwind' repos from the prior day, sending cash back to lenders and securities to dealers. The morning unwind provides dealers "access to their securities during the

^{vi} Note that the clearing process is outlined as it occurred before 2010.

business day, which they need to conduct their market-making activities or to meet their settlement obligations, while creating an exposure to the clearing bank secured by the portfolio of securities.”²² Ennis notes that “the reason why the clearing bank is (potentially) exposed to credit risk during the day is not because of the process of unwinding the repos in the morning itself, but because such unwinding is generally financed with intraday credit (an overdraft) extended by the clearing bank to the dealer.”²³ The overdraft by the clearinghouse is an extension of intraday credit to the dealer, similar to borrowing funds. It can originate at the initial request for funding by the dealer or because of unwinding outstanding repo transactions.²⁴ Most tri-party repos are open^{vii} or overnight, creating a heavy reliance on short-term financing.

Tri-party repos settle sequentially because trades agreed upon in the morning do not settle until the afternoon collateral allocation. Before 10 AM, roughly 80 to 95 percent of repos are arranged²⁵ and contracted in a Master Repurchase Agreement (MRA).^{viii} Around 5 PM, the afternoon collateral allocation takes place after the Fedwire Securities Service and the Depository Trust & Clearing Corporation close. At this time, the dealer knows the composition of its portfolio because securities can no longer be traded, and has already completed its market making activities and settlement obligations for the business day. The repo can then be ‘rewound’^{ix} by the clearing bank because the lender is now aware of how much financing or cash it can provide. Since the clearing bank provides financing services to its clients, the bank will rewind the repo once it understands the value of both the lender and dealer’s portfolios at the

^{vii} Open repos continue rolling forward until one party cancels the transaction.

^{viii} An MRA “specifies the amount of cash the investor will provide, the interest rate, and the term of the repo. The acceptable collateral for an agreement [CUA] also comes out of the appendix to the tri-party custodial agreement” (Copeland, Martin and Walker, The Tri-Party Repo Market before the 2010 Reforms 10). Terms set forth by the MRA and CUA can only be changed if approved by both the dealer and lender.

^{ix} Repos are rewound when the clearing banks send securities to the lender and cash to the dealer.

close of business. Finally, using the clearing banks' optimization tools and limits set forth in the Custodial Undertaking Agreement, the repo is rewound.²⁶

2.7 Players in the Tri-party Repo Market

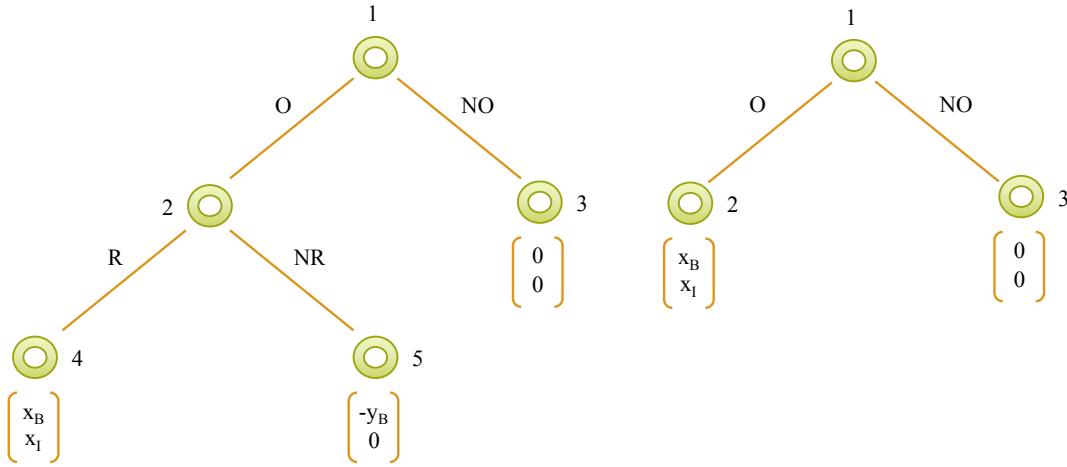
Ennis notes that the regular players in the tri-party repo market are clearinghouses (BNYM and JPMC), main broker dealers (securities dealers), and some large cash investors that participate everyday.²⁷ Each player's goal is to enter into a repo with a liquid counterparty that is currently not nor expected to be suffering from a solvency issue in the near future in order to avoid taking on credit risk. This creates dependence on symmetric information pertaining to the dealer's current liquidity standing. A firm's liquidity position is not synonymous with its reputation. During the financial crisis, Lehman Brothers suffered from reputation risk when news spread about its liquidity problems. Counterparty risk then caused Lehman to declare bankruptcy when its counterparties withdrew from the repo market. Therefore, the level of available information about a player's liquidity can determine its reputation and exacerbate counterparty risk. Perfect information is key for functioning credit channels. This, in turn, will determine the outcomes of games played in the tri-party repo market.

2.8 Strategic Interaction: Perception of Information

Perception played a critical role in the tri-party repo market during the crisis as beliefs concerning dealer solvency drove motivated players' strategic decisions rather than actual facts, which were largely unavailable due to information constraints. Ennis uses standard non-cooperative game theory to assess how changes in perception created sudden shocks to the market such as the clearing banks' role in the "game of withdrawing before the rest, which

appears to be a good representation of the situation that was present in the tri-party repo market during the recent financial crisis".²⁸ This situation is represented in Game 2b when the bank refuses to enter into a repo when it anticipates that the lender will not rewind the transaction in

Figure 2 "The game with no uncertainty: Game 1"²⁹



the afternoon. A discussion about the goals and incentives of each player in his three games will establish the foundation for a study of how and why asymmetric information about agency MBS could have collapsed the tri-party repo market if the FED had not intervened.

Game 1, which appears in figure 2, uses a very simple setting with one investor ($N=1$) that captures some of the factors influencing the market in order to study strategic interaction. Figure 2 illustrates sequential play with perfect information in Game 1:

First, consider the decision of the bank in the subgame that starts at node 4, that is, after investors have agreed to repo the securities. If the bank unwinds the repos, then it gets a payoff equal to x_B , which is greater than the payoff of zero obtained from not unwinding. Then, the bank will agree to unwind the repos. We can now write an auxiliary game tree that takes this result into account. This is the tree represented in the left-hand side of Figure 2. Following the same logic, we can now solve backward in this game to find that the investor will agree to repo the securities because $x_B > -y_B$. Finally, we can draw an auxiliary tree that incorporates this last result (on the right-hand side of Figure 2) and find that the bank will agree to grant an overdraft since $x_B > 0$. Hence, we have that the bank will always play O [overdraft], then the investor will

always play R [repo], and lastly the bank will always play U [unwind], which completes the proof of the proposition.³⁰

In Game 1, players move sequentially and have common knowledge.^x Common knowledge in Game 1 is the mutual belief among players that dealer solvency is not a threat so perfect information exists in the absence of external and strategic uncertainty.^{xi} Perfect information in the tri-party repo market prevents a run on repos because players use their dominant strategy^{xii} (O, R, U) to achieve subgame perfect Nash (SPN) equilibria.^{xiii}

2.9 External and Strategic Uncertainty

This section provides historical background about the role of informational asymmetries related to MBS during the crisis with respect to Ennis's Games.

Games 2a and 2b follow the same structure as Game 1, except information is imperfect. Game 2a^{xiv} features equal levels of uncertainty between the lender and clearing bank. It has the same unique SPN equilibria as Game 1 “[i]f the probability [p] of the dealer not experiencing a solvency problem is high enough … then the dealer will get funding from the bank and from the cash investor.”³¹ In Game 2a, the level of uncertainty about the dealer’s illiquidity is not high enough to cause deviation from the optimal path of play so the clearing bank and investor use their dominant strategy (O, R) to reach unique SPN equilibria.

^x “Common knowledge is usually defined as a state in which everyone knows that, everyone knows that everyone knows that, and so on, ad infinitum” (Ernst).

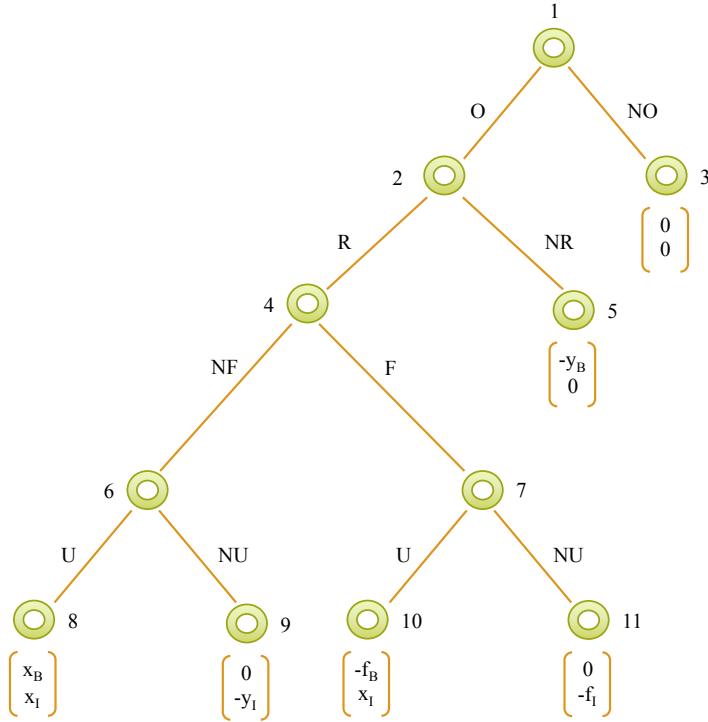
^{xi} Strategic uncertainty is “[a] player’s uncertainty about an opponent’s moves made in the past or made at the same time as her own” (Dixit, Skeath and Reiley, Jr. 773). External uncertainty is “[a] player’s uncertainty about external circumstances such as the weather or product quality” (Dixit, Skeath and Reiley, Jr. 762).

^{xii} “A strategy X is dominant for a player if, for each permissible strategy configuration of the other players, X gives him a higher payoff than any of his other strategies. (That is, his best response function is constant and equal to X)” (Dixit, Skeath and Reiley, Jr. 761).

^{xiii} Subgame perfect equilibrium is “[a] configuration of strategies (complete plans of action) such that their continuation in any subgame remains optimal (part of rollback equilibrium), whether that subgame is on-or-off-equilibrium. This ensures credibility of all strategies” (Dixit, Skeath and Reiley, Jr. 773). Nash equilibrium is “[a] configuration of strategies (one for each player) such that each player’s strategy is best for him, given those of the other players. (Can be in pure or mixed strategies)” (Dixit, Skeath and Reiley, Jr. 766).

^{xiv} Game 2a is not displayed because it is identical to Game 1 and yields the same equilibria.

Figure 3 “The Game with Uncertainty: Game 2b”³²



Game 2b, which appears in figure 3, exposes the vulnerabilities of clearing banks because of its daily credit exposure after it plays (O). However, this credit risk is mitigated when a clearing bank realizes the level of p before the morning unwind, giving it a strategic advantage:

The cash investor anticipates that the bank will be able to infer somehow, before the unwinding of the repos, the future performance of the dealer. If the investor believes that it is very likely that the bank will find out that the dealer is bound to fail (and hence that the bank will not unwind the repos), then the investor will not be willing to agree to the repo transaction. In turn, anticipating this, the bank will not grant an initial overdraft to the dealer and the whole tri-party repo arrangement collapses.³³

The original pure SPN equilibria^{xv} still exists. Additionally no overdraft (NO) is the second pure SPN equilibria. The bank now plays (NO) when it anticipates that lenders will play (NR) because “[there] is [a] loss [-y_B] to the exposed bank when the dealer fails … after unwinding the repos”.³⁴ Thus, the repo market collapses because no funding is provided to the dealer as shown in figure 3. It is significant that the market does not collapse upon the actual failure of the dealer, but rather upon the perception of dealer insolvency, such that it does not receive funding from the clearing bank. This was the case in March 2008, which led to the collapse of Bear Stearns, the fifth-largest domestic investment bank at the time.

The FED deemed Bear Stearns was “too interconnected to allow the investment house to fail”³⁵ due to its’ risky investments in subprime mortgage securities around the world. To minimize the fallout, on March 14, 2008 the FED approved JPMC’s acquisition of Bear Stearns. Two days later, on March 16th, the Federal Open Market Committee established the Primary Dealer Credit Facility (PDCF). At the time, the PDCF was defined as “an overnight loan facility that will provide funding to primary dealers in exchange for any tri-party-eligible collateral and is intended to foster the functioning of financial markets more generally.”³⁶ Initially, “PDCF credit extended by the Federal Reserve was fully collateralized … eligible collateral was restricted to investment-grade securities.”³⁷ However, as “the outstanding stock of agency MBS also increased significantly during the crisis period, from \$3.99 trillion at June 2007 to \$5.27 trillion by December 2009”,³⁸ contagion set in. Counterparty risk caused another Systemically Important Financial Institution to fail. Lehman Brothers filed for Chapter 11 bankruptcy

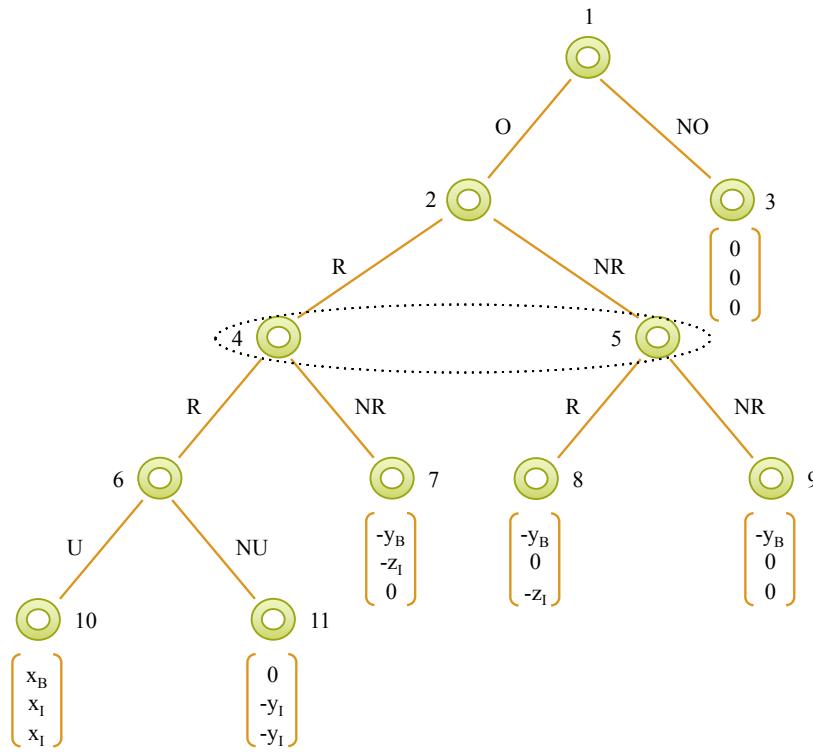
^{xv} A pure strategy is “[a] rule or plan of action for a player that specifies without any ambiguity or randomness the action to take in each contingency or at each node where it is that player’s turn or act” (Dixit, Skeath and Reiley, Jr. 770).

protection on September 15, 2008 (the largest bankruptcy in U.S. history). As a result, SIPC^{xvi} stepped in to protect customers when “the Trustee transferred more than 110,000 customer accounts, containing more than \$92 billion in customer assets, within weeks”.³⁹ Subsequently, Merrill Lynch approved its’ sale to Bank of America and American International Group, Inc. received massive loans up to \$85 billion as it failed to meet obligations. The markets had never seen such catastrophic loss, especially over a two-day period (September 15-16th). *The Wall Street Journal* reported that “[t]he American financial system was shaken to its core”.⁴⁰ Uncertainty continued to rise as the effects of Lehman’s collapse rippled throughout the financial system.

The FED observed clearinghouses playing (NO) over anticipation that investors would play (NR), as seen in Game 2b. Anticipation exacerbated liquidity pressures in the tri-party repo market days before Lehman’s failure. Similar to Game 2b, a dealer can collapse before it declares bankruptcy as a result of frozen credit channels because of insolvency threats. Consequently, coordinated (NR) moves among investors threatened the sustainability of the market. Game 3 demonstrates this situation among investors only.

Figure 4 “Coordination in the Repo Market: Game 3”⁴¹

^{xvi} SIPC or the Securities Investor Protection Corporation was established in 1970 through the Securities Investor Protection Act in order to “protect customers against certain types of loss resulting from broker-dealer failure and, thereby, to promote investor confidence in the nation’s securities markets” (SIPC).



Game 3 features two investors ($N=2$) in order to represent interactions among multiple lenders. Figure 4 illustrates Game 3 in its extensive form^{xvii} with an information set around nodes four and five. An information set is placed around two or more action nodes when players do not know which node they are moving at because they lack common knowledge about their opponent's simultaneous move. An information set “is the result of the fact that investors play simultaneously … each investor does not know if the other investor has played (R) or (NR) at the time that he has to decide what to play (that is, the investor does not know if he is in node 4 or in node 5, respectively).”⁴² The normal form game^{xviii} represents simultaneous play in Game 3 in figure 5.

^{xvii} Extensive form is “[r]epresentation of a game by a game tree” (Dixit, Skeath and Reiley, Jr. 762).

^{xviii} Normal form “[r]epresentation of a game in a game matrix, showing the strategies (which may be numerous and complicated if the game has several moves) available to each player along a separate dimension (row, column, etc.) of the matrix and the outcomes and payoffs in the multidimensional cells. Also called strategic form” (Dixit, Skeath and Reiley, Jr. 766-7).

Figure 5 “Normal Form Representation of the Coordination Game in the Repo Market”⁴³

		Investor 1	
		R	NR
Investor 2	R	x_I, x_I	$-z_I, 0$
	NR	$0, -z_I$	$0, 0$

Two pure-strategy SPN equilibria are possible in Game 3 (R, R) which yields payoffs equal to (x_I, x_I) while (NR, NR) results in $(0, 0)$. A once non-cooperative game shifts to coordination between players:

In the first case, when both investors agree to enter repo transactions, the bank will be willing to grant an overdraft (i.e., play O) in node 1. The equilibrium actions will then be $(O, \{R, R\}, U)$ and the equilibrium payoffs will be (x_B, x_I, x_I) .

In the other case, when investors play (NR, NR), we have that the bank will not agree to initially grant the overdraft and the equilibrium payoffs are equal to zero for all players since the dealer does not get funded from the outset.⁴⁴

The first case $(O, \{R, R\}, U)$ should always occur when information is symmetric and common knowledge exists because players use choose dominant strategy (O, R, R) to reach payoffs of (x_B, x_I, x_I) in this non-cooperative sequential game. Alternatively, the game of withdrawing before the rest occurs in Game 2b and Game 3. When information is asymmetric and players move based on anticipation in lieu of common knowledge, investors will not enter into repos. For example, when liquidity pressures about agency MBS intensified during the crisis, investors stopped playing (R) out of fear that they would enter into this contract with a potentially insolvent dealer. Therefore, coordinated simultaneous (NR) moves by investors caused the credit channel to freeze because players reached their pure SPN equilibria of $(0, 0)$, as seen in Game 3. This situation materialized when news spread about Lehman Brothers’ exposure to illiquid MBS. Coordinated (NR, NR) moves by investors caused Lehman to collapse overnight.

Like most financial intermediaries, Lehman depended on intraday credit to finance its' daily operations, made possible by functioning credit channels. Coordinated moves bankrupted Lehman overnight when “[frozen] markets [chocked] off the ability of companies and banks to borrow money and pay bills.”⁴⁵

When players trust their opponents, investors can reach the second pure SPN equilibria (x_I, x_I), which benefits everyone in Game 3. This second pure SPN equilibria is only possible by playing (R, R), a move that requires investors to trust that their opponents will not defect by playing (NR). This trust was shattered when insolvency news about Lehman and other large investment houses broke. The ability to obtain a payoff that makes all players better off, without hurting anyone else in the game is called Pareto improvement.^{xix} Pareto improvement was impossible after news spread because market participants were replete with fear that any institution holding MBS could experience liquidity problems instantaneously. Pareto improvement leads to superior Pareto optimality^{xx} of (x_I, x_I), assuming that rational players would have used their dominant strategy of (R). We assume that players exhibit bounded rational behavior within circumstance such that their actions will bring them closer to their goals.

The days leading up to the failure of Lehman created external uncertainty when players believed that they would be left holding illiquid securities if the dealer failed. Subsequently, PDCF “eligible collateral was expanded to match closely all of the types of instruments that can be pledged in the tri-party repurchase agreement system of the two major clearing banks”⁴⁶ on September 14th. Although this came too late to save Lehman, it did restore equilibria to the tri-

^{xix} “A change in the economy is said to represent a Pareto improvement if at least one person is made better off as a result of the change and no person is made worse off” (Zerbe 3).

^{xx} “A Pareto optimum is a state of affairs such that no one can be made better off without making someone else worse off” (Zerbe 3). “A potentially Pareto superior alternative to the status quo is created only when conditions change. A situation in which conditions change may justify a transition state of movement towards a new Pareto superior position ... [t]hat is, when one says that a change is efficient, it is an assertion of superior knowledge, or a plea for a new understanding that will then result in the proposed efficient change” (Zerbe 78).

party repo market by eliminating external uncertainty. It provided liquidity in the repo market so that:

[I]nvestors would get payoff x_1 from choosing (R), independent of what the other investor is choosing. This change in the structure of payoffs makes (R, R) the unique equilibrium of the game, and the dealer always gets funded. The key to this result is that the policy intervention changes the game among investors so that it is no longer a coordination game. Interestingly, in the model, the PDCF would not be tapped by investors in equilibrium, even though it is essential for ruling out the possibility of coordination failures and, in this way, stabilizing the market.⁴⁷

Since the PDCF was to be used by the dealer but through clearing banks, this suggests that confidence in clearing banks never deteriorated, but rather only at the dealer level.

The FED's move shifted the focus away from insolvency threats and towards normal repo activity by deescalating panic over agency MBS held by dealers. Furthermore, this move broke down coordinated simultaneous games, allowing for Pareto improvement such that investors returned to choosing their dominant strategy of (R). The FED used its' transparency tools to restore confidence in this short-term funding market by eliminating external and strategic uncertainty. The PDCF eliminated external uncertainty by reassuring primary dealers and their clients that repos would be rewound when dealers could borrow from the FED, through their clearing bank, if necessary.⁴⁸ Game 3 returned to the situation in Game 1 when dealer solvency threats no longer existed so players returned to their dominant strategy (O, R).

3 Methodology

In order to understand which quantitative variables influence the market's behavior and further support Ennis's game theoretic conclusions, I constructed three multiple regression models. Empirical results confirmed that real GDP and the collateral value of agency MBS significantly impact BNYM's share of worldwide tri-party repo balances. This evidence

supports Ennis's conjecture that the tri-party repo market is sensitive to information regarding players' perception about economic growth as well as the value of supporting collateral.

All models were estimated using OLS multiple regressions. Time series data were recorded from 2003 through 2014 on a quarterly basis.

Before the Federal Reserve Bank of New York began publishing monthly tri-party repo data in May 2010, these data were scarce because clearing repo and securities lending transactions were solely recorded on clearing banks' 10-K and 10-Q reports "to the extent that they occur on the balance sheet".⁴⁹ The 10-K and 10-Q reports for both JPMC and BNYM were examined for tri-party repo data for the entire dataset. However, each firm followed a different method for recording tri-party repos. Consequently, tri-party repo balances were only taken from BNYM's financial statements because the same line item, "share of worldwide tri-party repo balances" was available on every report. Therefore, BNYM's share of worldwide tri-party repos was used as a proxy for repo balances. Since BNYM "settle[s] securities transactions in over 100 markets and handle[s] most of the transactions cleared through the Federal Reserve Bank of New York for 17 of the 21 primary dealers ... [and has] approximately 84 percent of the market share of the U.S. tri-party repo market",⁵⁰ its market share is a worthy proxy for repo activity. BNYM's share of worldwide tri-party repo balances are recorded in trillions of U.S. dollars for the dependent variable.

Model one examined the relationship between perception of dealer and investor liquidity, monetary policy, and BNYM's share of worldwide tri-party repo balances. Two versions of the model were tested in order to compare two time periods. The first period was from 2008 through 2014 with twenty-seven observations, which was selected to examine the market after the

recession. The second period was from 2003 through 2014 with forty-three observations in order to obtain a longer perspective on market activity.

The Chicago Board Options Exchange (CBOE) Volatility Index (VIX) represents perception of dealer and investor liquidity. The VIX is “a key measure of market expectations of near-term volatility conveyed by S&P 500 stock index option prices … VIX has been considered by many to be the world's premier barometer of investor sentiment and market volatility”.⁵¹ The CBOE publishes the VIX. It is measured by an index in which values greater than thirty reflect higher than normal levels of volatility because of investor fear or uncertainty while values below twenty signal subdued market volatility. I expected to find an inverse relationship between tri-party repo balances and the VIX. When investors have a positive outlook on the economy, the VIX should tick down while tri-party repo balances move up because participants are more likely to invest.

The three-month U.S. treasury yield represents monetary policy at the end of the period on a quarterly basis and is published by the Board of Governors of the Federal Reserve System. Treasury bonds are virtually riskless short-term financial instruments, backed by U.S. government debt obligations. Since treasury bills trade at the federal funds rate, accommodative monetary policy influences the yield. The FED’s accommodative policy stance has put downward pressure on long-term treasuries, decreasing short-term yields while holding the federal funds rate at the zero lower bound. Therefore, low yields in the bond market should force investors, seeking higher yield returns, into the stock market and other higher yield investments. If investors are confident enough to adjust their portfolios, the treasury yield should drop further. During times of elevated market volatility investors exit the stock market and flock to high yield bonds, according to the flight-to-quality theory. Additionally, since the term to

maturity on the three-month note is less than one-year, interest rate risk is minimal. Minimal interest rate risk makes the three-month yield a safe haven for those unwilling to invest in long-term bonds. I expected to find an indirect relationship between the three-month treasury yield and worldwide tri-party repo balances. If the yield ticks down, tri-party repo activity should increase while the VIX falls.

Model two tested if perception of dealer and investor liquidity, monetary policy, real GDP, and MBS significantly impact tri-party repo market activity. This model had a sample size of eighteen and covers the period from 2010 through 2014.

Real GDP data are recorded by the Bureau of Economic Analysis, U.S. Department of Commerce. The data values reflect seasonally adjusted, annualized GDP in billions of U.S. dollars on a quarterly basis. Real GDP reveals changes in economic growth trends, which affect the stock and bond markets. When lower than expected GDP is reported and economic growth slows, investors typically pull out of the stock market and re-enter the bond market. For example, on Friday, January 30, 2015, real GDP “increased at an annual rate of 2.6 percent in the fourth quarter of 2014, according to the ‘advance’ estimate released by the Bureau of Economic Analysis. In the third quarter, real GDP increased 5.0 percent.”⁵² Following this news,

U.S. stocks moved lower on Friday and were on track to end January with its biggest monthly loss in 12 months. Investors flocked into havens such as Treasuries and sold equities after government data showed the economy slowed down in the fourth quarter by more than had been expected.⁵³

This indicator provides insight about how tri-party repo balances change because real GDP modifies the market’s behavior. I expected to find a direct relationship between repo balances and real GDP. Positive expectations about economic growth should pull investors out of the bond market and push them towards the stock market and other higher yield investments.

In order to measure the relationship between tri-party repos and MBS, the following variables were tested using quarterly data. (1) The collateral value of agency MBS for tri-party repos, published by the Federal Reserve Bank of New York in billions of U.S. dollars. (2) Mortgage-related agency securities outstanding in billions of U.S. dollars, published by Thomson Reuters Eikon, Bloomberg, Fitch Ratings, Moody's, S&P, and the Securities Industry and Financial Markets Association (SIFMA). (3) All MBS and other guarantees outstanding held by third parties in millions of U.S. dollars, published by Thomson Reuters Eikon, Bloomberg, Fitch Ratings, Moody's, S&P, and SIFMA. (4) All maturities of MBS held by the Federal Reserve, in millions of U.S. dollars, published by the Board of Governors of the Federal Reserve System. (5) All maturities of federal agency debt securities held by the Federal Reserve in millions of U.S. dollars, published by the Board of Governors of the Federal Reserve System. These variables were studied to further consider the informational asymmetries regarding securities dealers with illiquid MBS during the financial crisis. A significant MBS variable supported Ennis's assumption that market participants make decisions based on their perception of counterparty liquidity positions.

The parsimonious model tested if real GDP and agency MBS collateral value significantly impact tri-party repo market activity. The sample included seventeen observations from 2010 through 2014.

4 Quantitative Analysis

4.1 Model One

Model one tested if perception of dealer and investor liquidity and monetary policy have a significant impact on worldwide tri-party repo market balances. Table 1 shows the results of

model one. The model was run twice, from 2Q of 2008 through 3Q of 2014 and from 1Q of 2003 through 1Q of 2014.

	TPR, 2Q 2008 – 3Q 2014	TPR, 1Q 2003 – 3Q 2014
VIX	-0.006 (-1.68)	0.002 (0.32)
Yield	-0.095 (-1.84)	-0.153 (-4.98)**
Constant	2.051 (23.75)**	1.881 (12.23)**
R^2	0.27	0.43
Adjusted R^2	0.20	0.40
F model	4.35	15.07
P-value of F model	0.02	0
Observations	27	43

T-statistics are in parentheses. * $p < 0.05$; ** $p < 0.01$

Note: “TPR” refers to BNYM’s share of worldwide tri-party repo balances.

Table 1: Results of model one.

The results of model one produced the following equation, the standard errors in parentheses:

$$TPR_{t=2008-14} = 2.051 - 0.006VIX_t - 0.095Yield_t$$

(0.003)	(0.052)
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A one percent increase in the VIX leads to a \$6 billion decrease in tri-party repo balances, holding the three-month treasury yield constant. As expected, elevated levels of perceived market volatility diminish tri-party repo market activity. Concurrently, a one percent increase in the three-month treasury yield leads to a \$95 billion decline in tri-party repo balances, holding the VIX constant. This result also corresponds to my expectation that an uptick in the treasury yield occurs alongside a reduction in tri-party repo market activity, representing a flight-to-quality situation. Furthermore, the treasury yield affects the volume of tri-party repos more than the VIX, thus perception may be less prevalent than the effects of accommodative monetary

policy. Although these inferences suggest that I may reject the null hypothesis, deeper statistical inference is necessary to determine the validity of these findings.

A low R^2 and adjusted R^2 suggest that these data poorly fit the model. R^2 implies that only 27% of the variability around tri-party repo balances between 2Q 2008 and 3Q 2014 can be attributed to the volatility around each X-variable. The adjusted R^2 indicates that merely 20% of volatility around the Y-variable can be explained by the independent variables. The small sample size of twenty-seven observations could be the root cause of these inconsistencies. Additionally, a two-tailed t-test produced a t -critical $_{0.025,25}$ value of 1.71, proving the coefficients insignificant.

To explain more of the volatility around the dependent variable, the entire dataset was regressed to retest model one. The results of the model, with a time-period from the first quarter of 2003 through the third quarter of 2014, are as follows. The standard errors are recorded in parentheses.

$$TPR_{t=2003-14} = 1.881 + 0.002VIX_t - 0.153Yield_t \\ (0.006) \quad (0.031)$$

A one percent increase in the VIX leads to a \$2 billion rise in tri-party repo balances, holding the three-month treasury yield constant. This result is contradictory to my expectation that perception and tri-party repo activity are inversely related. On the contrary, a one percent increase in the three-month treasury yield leads to a \$153 billion reduction in tri-party repo balances, holding the VIX constant. While this equation had a larger dataset and improved statistical fit in comparison to the smaller sample, it contradicts my expectations insofar that I may fail to reject the null hypothesis.

The R^2 and adjusted R^2 have increased since the last run of the model but still fail to explain more than 50% of the volatility around the dependent variable. While R^2 indicates that

43% of the variability around tri-party repo balances, between 1Q 2003 and 3Q 2014, can be accredited to the volatility around perception and accommodative monetary policy; the adjusted R^2 communicates that 40% of volatility around the dependent variable can be explained by the independent variables. Furthermore, a *t-critical* $_{0.025,41}$ of 1.68 is greater than each independent variable's t-score. Therefore, the coefficients are insignificant so I fail to reject the null hypothesis.

Although these preliminary statistics cannot yet prove Ennis's game theoretic findings, tests for heteroskedasticity, multicollinearity, and autocorrelation were conducted to meet the classical assumptions of regression analysis. Neither model shows signs of heteroskedasticity according to two-tailed χ^2 tests. Since χ^2 critical values are above the χ^2 calculated values, each model has constant variance so the dependent variables' variance is equal across each independent value. Multicollinearity is another concern when running regression models. Therefore, the Variance Inflation Factor (VIF) is a useful statistic in understanding the relationship between the independent variables. Since the VIF scores are all below ten while the t- and & F-tests agree, multicollinearity is not a concern in either regression. Autocorrelation can cloud inferences about a model when each independent variable cannot be evaluated individually because it is correlated with the dependent variable. Both models have positive Durbin-Watson d-statistics around 0.38, which indicates positive serial correlation. However, after adjusting the linear model for autocorrelation in the error terms using Cochrane-Orcutt estimation, both models show improved d-statistics.

Model one failed to prove that perception of dealer and investor liquidity and monetary policy significantly impact the tri-party repo market both after the PDCF and throughout the entire dataset. Thus far, only game theoretic findings explain why participants act on

anticipation rather than facts when dealer solvency causes informational asymmetries. So far, it is not evident that a breakdown of trust in the market caused players to defect because of strategic and external uncertainty. Therefore, adding more variables to the equation may provide more detail about how tri-party repo market participants estimate their payoffs and determine their moves.

4.2 Model Two

Hypothesis two tested if perception of dealer and investor liquidity, expectations about economic growth, monetary policy, and MBS significantly influence tri-party repo market activity. Real GDP was added to the model to examine how market participants react to an economic growth indicator and measure expectations. Additionally, various MBS were tested in this model as well.

Five different variables representing MBS were regressed alongside the VIX, real GDP, and three-month treasury yield on BNYM's share of tri-party repo balances worldwide. MBS variables included the level of collateral value of agency MBS for tri-party repos, mortgage-related agency securities outstanding, all MBS and other guarantees outstanding held by third parties, all maturities of MBS held by the Federal Reserve, and all maturities of federal agency debt securities held by the Federal Reserve. After running each MBS variable, I found that every MBS variable was insignificant except for the level of collateral value of agency MBS for tri-party repos. Table 2 includes the results of model two with agency MBS collateral value, the other insignificant MBS variables are included in figure 6 of the appendix.

	TPR
VIX	-0.003 (-1.10)
GDP	0.0002

	(6.67)**
Yield	0.052
	(0.55)
MBS collateral value	0.008
	(2.77)*
Constant	-1.007
	(-2.00)
R^2	0.90
Adjusted R^2	0.86
F test model	28.06
P-value of F model	0
Observations	18

T-statistics are in parentheses. * $p<0.05$; ** $p<0.01$

Table 2: Model two results.

This model included tri-party repo data collected by the Federal Reserve Bank of New York, which was collected from May 2010 through September 2014. There are eighteen observations. Thus, finding significant results from this small sample size was unexpected. The following model reports that by holding all else constant, the independent variables produce significant results. A one percent rise in the VIX leads to a \$3 billion reduction in BNYM's share of tri-party repo balances. This supports the flight-to-quality theory that investors will retreat from stocks and invest in bonds when perceived market volatility ticks up. Concurrently, a \$1 billion increase in real GDP returns a \$200 million increase in tri-party repo balances while a one percent increase in the three-month treasury yield shows a \$50 billion uptick in tri-party repo balances. This evidence seems to support the flight-to-quality theory for real GDP but fails to meet my expectation that tri-party repo balances and the three-month yield are inversely related. Additionally, a \$1 billion increase in agency MBS used to collateralize tri-party repo transactions leads to an increase of \$8.1 billion in BNYM's share of tri-party repo balances. Such a large swing in repo balances could support the idea that the tri-party repo market is sensitive to information about supporting repo collateral. The following equation represents these findings; the standard errors are recorded in parentheses.

$$TPR_{t=2010-14} = -1.01 - 0.003VIX_t + 0.0002GDP_t + 0.05Yield_t + 0.0081MBS_t$$

(0.003)	(0.00003)	(0.095)	(0.0003)
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The empirical results of this model show that these data fit the model well. R^2 reveals that 90% of the variability around tri-party repo balances can be attributed to the volatility around the dependent variable. The adjusted R^2 implies 86% of volatility around Y can be explained by X. However, a two-tailed t-test shows that the VIX and three-month yield are insignificant, given their t -critical $_{0.025,14}$ values are below the t-statistics shown in table 2. Upon further investigation, two tailed χ^2 tests report that heteroskedasticity is not a concern since the χ^2 critical equals 23.68, which is greater than the χ^2 calculated value of 3.70. Furthermore, the model does not suffer from multicollinearity because the t-and F-tests agree and all VIF's are below ten. Additionally, a Durbin-Watson statistic of 1.6 is between the lower (0.92) and upper (1.87) bounds of the d-statistic interval. Therefore, the autocorrelation test is inconclusive. These results led me to construct a parsimonious model to study real GDP and agency MBS collateral value without possible noise from the VIX and treasury yield since the autocorrelation test was inconclusive.

4.3 Parsimonious Model

The parsimonious model is the most simplified model with as few predictor variables as possible. The VIX and treasury yield were eliminated in order to test if expectations about economic growth and agency MBS collateral value significantly impact BNYM's share of worldwide tri-party repo balances. The empirical results are logged in table 3 and tri-party repo balances were regressed in billions of U.S. dollars.

	TPR	TPR, Cochrane-Orcutt Iterated Estimates
GDP	0.167	0.141

MBS collateral value	(9.07)** 0.698 (4.39)**	(6.52)** 0.599 (3.57)**
Constant	-1,205.699 (3.95)**	-717.855 (1.93)
R^2	0.88	0.79
Adjusted R^2	0.86	0.76
F test model	53.50	25.81
P-value of F model	0	0
Observations	18	17

T-statistics are in parentheses. * $p<0.05$; ** $p<0.01$

Table 3: Parsimonious model results.

The parsimonious model was run twice. The first iteration of the regression returned inconclusive serial correlation results with a d-statistic of 1.3, which sits within the lower (0.95) and upper (1.54) bounds of the Durbin-Watson interval. However, after adjusting the equation for autocorrelation in the error terms using Cochrane-Orcutt estimation, the parsimonious model shows an improved d-statistic of 2.11. Since the transformed d-static is greater than the upper bound, the model does not suffer from autocorrelation. The following interpretation will focus on the regression results after autocorrelation was corrected. This equation represents the parsimonious model results, the standard errors are recorded in parentheses.

$$TPR_{t=2010-14} = -717.86 + 0.141GDP_t + 0.599MBS_t \\ (0.02) \quad (0.17)$$

The equation shows that a \$1 billion increase in real GDP leads to \$141 million rise in tri-party repo activity, holding agency MBS collateral value constant. This outcome reflects my expectation that investors will gain more confidence in the market when elevated real GDP figures are released. Concurrently, a \$1 billion increase in agency MBS used to collateralize tri-party repo transactions leads to an increase of \$599 million in tri-party repo balances, holding real GDP constant. The parsimonious model seems to support the flight-to-quality theory, which

may suggest that these independent variables affect tri-party repo market participants' moves throughout the clearing process.

R^2 indicates that 79% of the volatility around tri-party repo balances can be attributed to the variability around X. The adjusted R^2 denotes that 76% of the volatility around Y can be explained by real GDP and agency MBS collateral value. The adjusted R^2 is especially noteworthy because it takes into consideration missing data and offers more detail than R^2 about what factors interact with the dependent variable. Since the adjusted R^2 shows that the parsimonious model fits the data well, a two-tailed t-test was conducted. The t -critical $_{0.025,15}$ equals 1.75, which is less than the t-statistics reported in table 3. This verifies that the estimated coefficients are in fact statistically significant. The p-values are also less than alpha of 5%. Additionally, the F-test and t-test were conclusive, alongside low VIF scores, below ten, which rule out multicollinearity. Therefore, the independent variables are not functions of one another. Moving along, a two-tailed χ^2 test for heteroskedasticity demonstrates that a constant variance exists among the dependent variables at each independent value because the χ^2 critical of 25 is greater than the χ^2 calculated at 5.44. Finally, I will reject the null hypothesis that real GDP and agency MBS collateral value do not significantly impact worldwide tri-party repo balances held by BNYM.

5 Results

Three regression models examined how perception of dealer and investor liquidity, monetary policy, expectations about economic growth, and MBS valuation impact BNYM's worldwide share of tri-party repo balances.

The VIX and three-month treasury yield did not have a significant impact on tri-party repo market activity. I expected that the FED's accommodative monetary policy, which has put downward pressure on treasury yields would have incentivized players to exit the bond market and re-enter the stock market or other higher yielding investments. However, it seems that repo market participants do not consider the three-month treasury yield when formulating strategic moves because BNYM's share of worldwide tri-party repo balances were largely unaffected by this variable. One might expect that dealers may use repos to finance additional equity transactions on behalf of their clients, but this does not appear to be the case. In addition, the VIX may not be a reliable estimator for perception of dealer and investor liquidity in this market. Investors may not consider the VIX when choosing strategies throughout the clearing process since it had an insignificant impact on repo balances. Therefore, I believe that the VIX and three-month treasury yield are irrelevant to consider when examining what variables motivate player's moves in Ennis's games. It is certainly possible that these factors do influence the tri-party repo market but their effects are not captured by the variables chosen.

These unexpected results led me to add real GDP and MBS variables to the second model in order to test the flight-to-quality theory and whether MBS were significant. Of the five MBS variables tested (mortgage-related agency securities, all MBS and other guarantees outstanding held by third parties, all maturities of MBS held by the FED, and all maturities of federal agency debt securities held by the FED), only agency MBS collateral value for tri-party repos was significant. This result was not surprising since Ennis proposed that investors largely withdrew from the tri-party repo market over fear that they would be entering into a repo with a potentially insolvent dealer. If the dealer defaulted after the afternoon collateral allocation, the investor would have been left holding illiquid collateral. MBS were responsible for much of the panic

during the crisis, especially since Bear Stearns and Lehman Brothers suffered crippling losses and liquidity problems over their exposure to MBS. The significance of agency MBS collateral upholds Ennis's conjecture that the tri-party repo market is sensitive to information. In particular, it seems to be sensitive to internal information about supporting repo collateral provided by dealers and external information about economic growth via real GDP. The significance of real GDP, confirmed my expectation that real GDP has a positive relationship with repo activity per the flight-to-quality theory. When positive real GDP figures are released, investors generally re-enter the stock market or higher yielding investments and drop out of the bond market.

6 Conclusion

BNYM's share of worldwide tri-party repo balances was used as a proxy to measure changes in domestic tri-party repo market activity in relation to real GDP and agency MBS collateral value. These factors influence how players make strategic decisions in the tri-party repo market that may result from changes in expectations about economic growth and supporting repo collateral. These results validate Ennis's conjecture that clearing banks, cash investors, and securities dealers will use their dominant strategies resulting in a subgame perfect Nash equilibrium when there is symmetric information about counterparty solvency, as seen in Game 1.

These results, which link game theory and regression analysis, can be applied to stress testing financial institutions. Annual stress tests aim “to ensure that large financial institutions have

robust, forward-looking capital planning processes that account for their unique risks, and to help ensure that they have sufficient capital to continue operations throughout times of economic and financial stress”.⁵⁴ I propose that stress scenarios reach beyond capital planning in order to consider behavioral factors that may alter the normal structure of the repo market during times of stress. If the FED can understand how firms will react, contingency planning can be built into stress testing in order to avoid a run on repos, which occurred during the financial crisis within the tri-party repo market. This would allow the FED to take into account the behavioral dimensions of market shifts in understanding the overall impact on tri-party repo market structure and future performance. Dynamic stress testing should consider changes in expectations and supporting repo collateral as variables to compliment forward-looking capital planning and implement contingency plans for behavioral shifts of market participants in the tri-party repo market to minimize panic during future crises.

Works Cited

- Adrian, Tobias, Christopher R. Burke and James J. McAndrews . "The Federal Reserve's Primary Dealer Credit Facility ." Current Issues in Economics and Finance 15.4 (2009).
- Adrian, Tobias, et al. "Repo and Securities Lending." Staff Report. 2013.
- Akerlof, George A. "The Market for "Lemons": Quality Uncertainty and the Market Mechanism." The Quarterly Journal of Economics 84.3 (1970): 488-500.
- Autor, David H. "Lecture Note: Market Signaling — Theory and Evidence." Massachusetts Institute of Technology, 2003.
- Bank of New York Mellon. FORM 10-K For the Fiscal Year Ended December 31, 2013. 10-K. NY, 2-13.
- Begalle, Brian, et al. "The Risk of Fire Sales in the Tri-Party Repo Market." Staff Report. 2013.
- Board of Governors of the Federal Reserve System. Press Release. 23 October 2014. 13 February 2015 <<http://www.federalreserve.gov/newsevents/press/bcreg/20141023a.htm>>.
- . Regulatory Reform: Primary Dealer Credit Facility (PDCF). 2 August 2013. 7 October 2014 <http://www.federalreserve.gov/newsevents/reform_pdcf.htm>.
- Bureau of Economic Analysis. "National Economic Accounts." U.S. Department of Commerce, 2014.
- Carrick Mollenkamp, Susanne Craig, Serena NG and Aaron Lucchetti. "Lehman Files for Bankruptcy, Merrill Sold, AIG Seeks Cash." Wall Street Journal 16 September 2008.
- Chicago Board Options Exchange. CBOE Volatility Index (VIX) Futures. 2014. 8 October 2014 <http://cfe.cboe.com/Products/Spec_VIX.aspx>.
- . CBOE Volatility Index (VIX) Futures. 22 October 2014 <http://cfe.cboe.com/products/spec_vix.aspx>.
- . Introduction to VIX Options. 2014. 8 October 2014 <<http://www.cboe.com/micro/VIX/vixoptions.aspx>>.
- . Introduction to VIX Options and Futures. 2014. 8 October 2014 <<http://www.cboe.com/micro/VIX/vixintro.aspx>>.
- Consumer Financial Protection Bureau. Mortgages. 30 December 2013. 11 November 2014 <<http://www.consumerfinance.gov/askcfpb/104/what-is-a-balloon-loan.html>>.
- Copeland, Adam, Antoine Martin and Michael Walker. "The Tri-Party Repo Market before the 2010 Reforms." Staff Report. 2010.
- Copeland, Adam, et al. "Key Mechanics of the U.S. Tri-Party Repo Market." Federal Reserve Bank of New York, 2012.
- . "Lifting the Veil on the U.S. Bilateral Repo Market." 9 July 2014. Liberty Street Economics. Federal Reserve Bank of New York. 29 September 2014 <<http://libertystreeteconomics.newyorkfed.org/2014/07/lifting-the-veil-on-the-us-bilateral-repo-market.html#.VCWBvStdWPq>>.
- . "Mapping and Sizing the U.S. Repo Market." 25 June 2012. Liberty Street Economics. Federal Reserve Bank of New York. September 29 2014 <<http://libertystreeteconomics.newyorkfed.org/2012/06/mapping-and-sizing-the-us-repo-market.html#.VCWF4StdWPo>>.
- Craig, Susanne and Mike Spector. "Repos Played a Key Role in Lehman's Demise." Wall Street Journal 13 March 2010.
- Curtin, Richard T. "Surveys of Consumers." Surveys of Consumers. 2012.

- Dimarco, Chris. "JPMorgan settles MBS class action lingering from Bear Stearns acquisition." Inside Counsel (2015).
- Dixit, Avinash, Susan Skeath and David H. Reiley, Jr. Games of Strategy. Third. New York: W.W. Norton & Company, Inc., 2009.
- Duffie, Darrell. "Replumbing Our Financial System: Uneven Progress." Stanford University, 2012.
- Ennis, Huberto M. "Strategic Behavior in the Tri-Party Repo Market." Economic Quarterly 97.4 (2011): 389-413.
- Ernst, Zachary. "What Is Common Knowledge?" Episteme 8.3 (2011).
- Federal Reserve Bank of New York. Primary Dealer Credit Facility: Frequently Asked Questions. 3 February 2009. 13 October 2014 <http://www.newyorkfed.org/markets/pdcf_faq.html>.
- . "Tri-party Repo Infrastructure Reform." n.d.
- . Tri-party Repo Statistical Data. 2010-2014. 29 September 2014 <http://www.newyorkfed.org/banking/tpr_infr_reform_data.html>.
- Ginnie Mae & the GSEs. 25 February 2013. 6 October 2014 <http://www.ginniemae.gov/consumer_education/Pages/ginnie_mae_and_the_gses.aspx>.
- Gorton, Gary and Andrew Metrick. "Haircuts." Federal Reserve Bank of St. Louis Review 92.6 (2010): 507-519.
- Herweg, Fabian and Daniel Müller. "Overconfidence in the Market for Lemons." Munich Discussion Paper. University of Munich, 2011.
- In re Lehman Brothers Mortgage-based Securities Litigation. No. 08-CV-6762. U.S. District Court, Southern District of New York. 22 June 2012.
- International Capital Market Association. 1. What is a repo? 2014. 2 October 2014 <<http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/short-term-markets/Repo-Markets/frequently-asked-questions-on-repo/1-what-is-a-repo>>.
- Ivry, Bob, Mark Pittman and Christine Harper. "Sleep-At-Night-Money Lost in Lehman Lesson Missing \$63 Billion." Bloomberg News 8 September 2009.
- Merrill Lynch Mortgage Pass-Through Litigation. No. 1:08-cv-10841-JSR. United States District Court, Southern District of New York. 16 December 2008.
- Mishkin, Frederic S. The Economics of Money, Banking & Financial Markets. 9th. Boston: Pearson Education Inc., 2010.
- Morgenson, Gretchen and Joshua Rosner. Reckless Endangerment. New York: St. Martin's Press, 2011.
- National Bureau of Economic Research. US Business Cycle Expansions and Contractions. 20 September 2010. 29 September 2014 <<http://www.nber.org/cycles.html>>.
- "National Income and Product Accounts, Gross Domestic Product: Fourth Quarter and Annual 2014 Advance Estimate." U.S. Department of Commerce, 2015.
- Robb, Greg. "Fed says Bear Stearns too interconnected to fail." The Wall Street Journal 27 June 2008.
- S&P Dow Jones Indices LLC. "S&P/Case-Shiller U.S. National Home Price Index." 2014.
- "SEC Enforcement Actions: Addressing Misconduct That Led To or Arose From the Financial Crisis." Key Statistics (through September 11, 2014). U.S. Securities and Exchange Commission, 2014.

SIPC. History and Track Record. 1 December 2014 <<http://www.sipc.org/about-sipc/history>>.

Sjolin, Sara and Anora Mahmudova. "U.S. stocks under pressure following weak GDP data." Market Watch 30 January 2015.

Twomey, Brian. Inside the Currency Market: Mechanics, Valuation and Strategies. Hoboken: John Wiley & Sons, Inc., 2012.

University of Michigan. "Survey of Consumers." Index of Consumer Sentiment. Thomson Reuters & University of Michigan, 2014.

Vickery, James and Joshua Wright. "TBA Trading and Liquidity in the Agency MBS Market." FRBNY Economic Policy Review (2013).

Zerbe, Richard O. Economic Efficiency in Law and Economics. Northampton: Edward Elgar Publishing, 2002.

¹ (Mishkin 304)

² (Morgenson and Rosner 25)

³ (Morgenson and Rosner 26)

⁴ (S&P Dow Jones Indices LLC)

⁵ (Twomey)

⁶ (Ginnie Mae & the GSEs)

⁷ (SEC Enforcement Actions: Addressing Misconduct That Led To or Arose From the Financial Crisis)

⁸ (SEC Enforcement Actions: Addressing Misconduct That Led To or Arose From the Financial Crisis)

⁹ (SEC Enforcement Actions: Addressing Misconduct That Led To or Arose From the Financial Crisis)

¹⁰ (Merrill Lynch Mortgage Pass-Through Litigation)

¹¹ (Merrill Lynch Mortgage Pass-Through Litigation)

¹² (In re Lehman Brothers Mortgage-based Securities Litigation)

¹³ (Dimarco)

¹⁴ (Adrian, Begalle and Copeland 1)

¹⁵ (Begalle, Martin and McAndrews 5)

¹⁶ (International Capital Market Association)

¹⁷ (Gorton and Metrick 519)

¹⁸ (Copeland, Duffie and Martin 18)

¹⁹ (Copeland, Duffie and Martin 19)

²⁰ (Adrian, Begalle and Copeland 14)

²¹ (Copeland, Davis and LeSueur, Lifting the Veil on the U.S. Bilateral Repo Market)

²² (Copeland, Martin and Walker, The Tri-Party Repo Market before the 2010 Reforms 10)

²³ (Ennis 394)

²⁴ (Ennis 406)

²⁵ "Key Mechanics of the U.S. Tri-Party Repo Market" reports 80 to 90 percent (Copeland, Duffie and Martin 23) of repos are arranged before 10 AM while "The Tri-Party Repo Market before the 2010 Reforms" claims that 90 to 95 percent (Copeland, Martin and Walker, The Tri-Party Repo Market before the 2010 Reforms 10) of repos are settled before 10 AM.

²⁶ (Copeland, Martin and Walker, The Tri-Party Repo Market before the 2010 Reforms 11)

²⁷ (Ennis 394)

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- ²⁸ (Ennis 390)
- ²⁹ (Ennis 397)
- ³⁰ (Ennis 398)
- ³¹ (Ennis 399)
- ³² (Ennis 401)
- ³³ (Ennis 401-02)
- ³⁴ (Ennis 399)
- ³⁵ (Robb)
- ³⁶ (Federal Reserve Bank of New York)
- ³⁷ (Board of Governors of the Federal Reserve System)
- ³⁸ (Vickery and Wright 1)
- ³⁹ (SIPC)
- ⁴⁰ (Carrick Mollenkamp)
- ⁴¹ (Ennis 404)
- ⁴² (Ennis 404)
- ⁴³ (Ennis 405)
- ⁴⁴ (Ennis 405)
- ⁴⁵ (Ivry, Pittman and Harper)
- ⁴⁶ (Board of Governors of the Federal Reserve System)
- ⁴⁷ (Ennis 406)
- ⁴⁸ (Adrian, Burke and McAndrews , The Federal Reserve's Primary Dealer Credit Facility 9)
- ⁴⁹ (Adrian, Begalle and Copeland 14)
- ⁵⁰ (Bank of New York Mellon 25)
- ⁵¹ (Chicago Board Options Exchange)
- ⁵² (National Income and Product Accounts, Gross Domestic Product: Fourth Quarter and Annual 2014 Advance Estimate)
- ⁵³ (Sjolin and Mahmudova)
- ⁵⁴ (Board of Governors of the Federal Reserve System)

Appendix

Figure 1
Repurchase Agreement (Begalle, Martin and McAndrews 5)

Opening Leg



Closing Leg



Figure 2
“Solving for the SPN Equilibrium of Game 1” (Ennis 398)

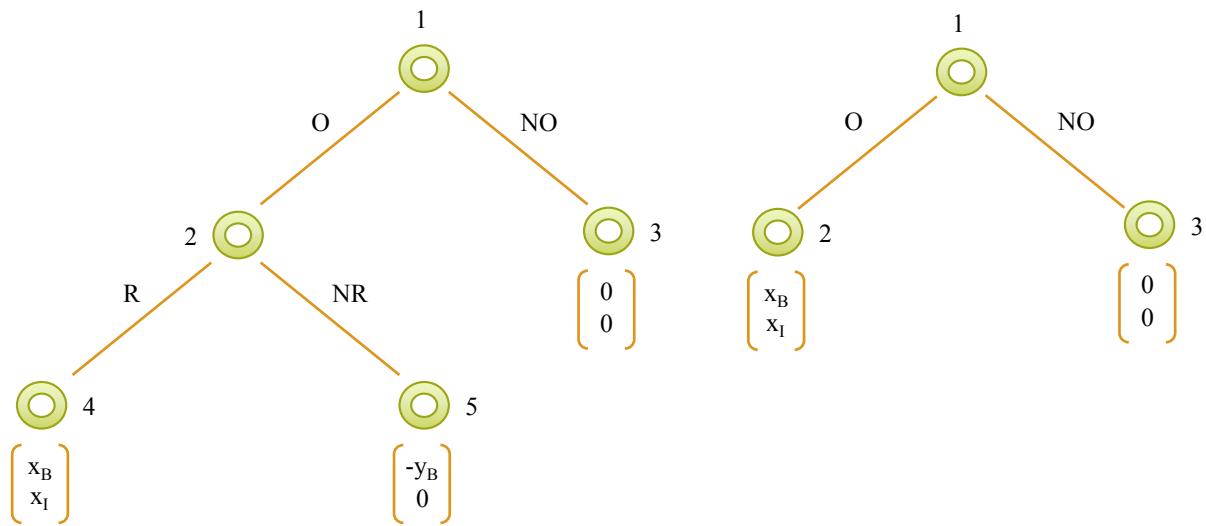


Figure 3
 “The Game with Uncertainty: Game 2b” (Ennis 401)

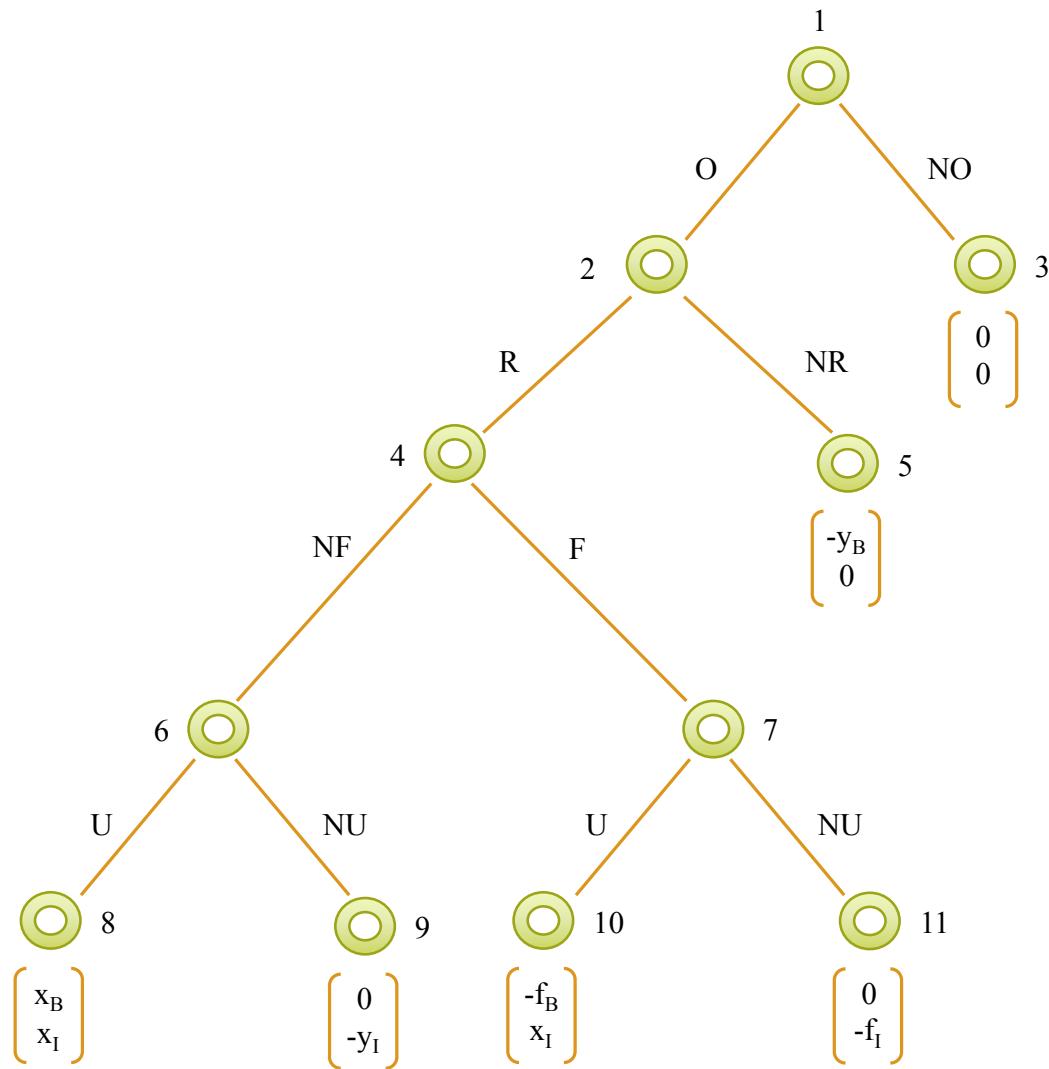


Figure 4
 “Coordination in the Repo Market: Game 3” (Ennis 404)

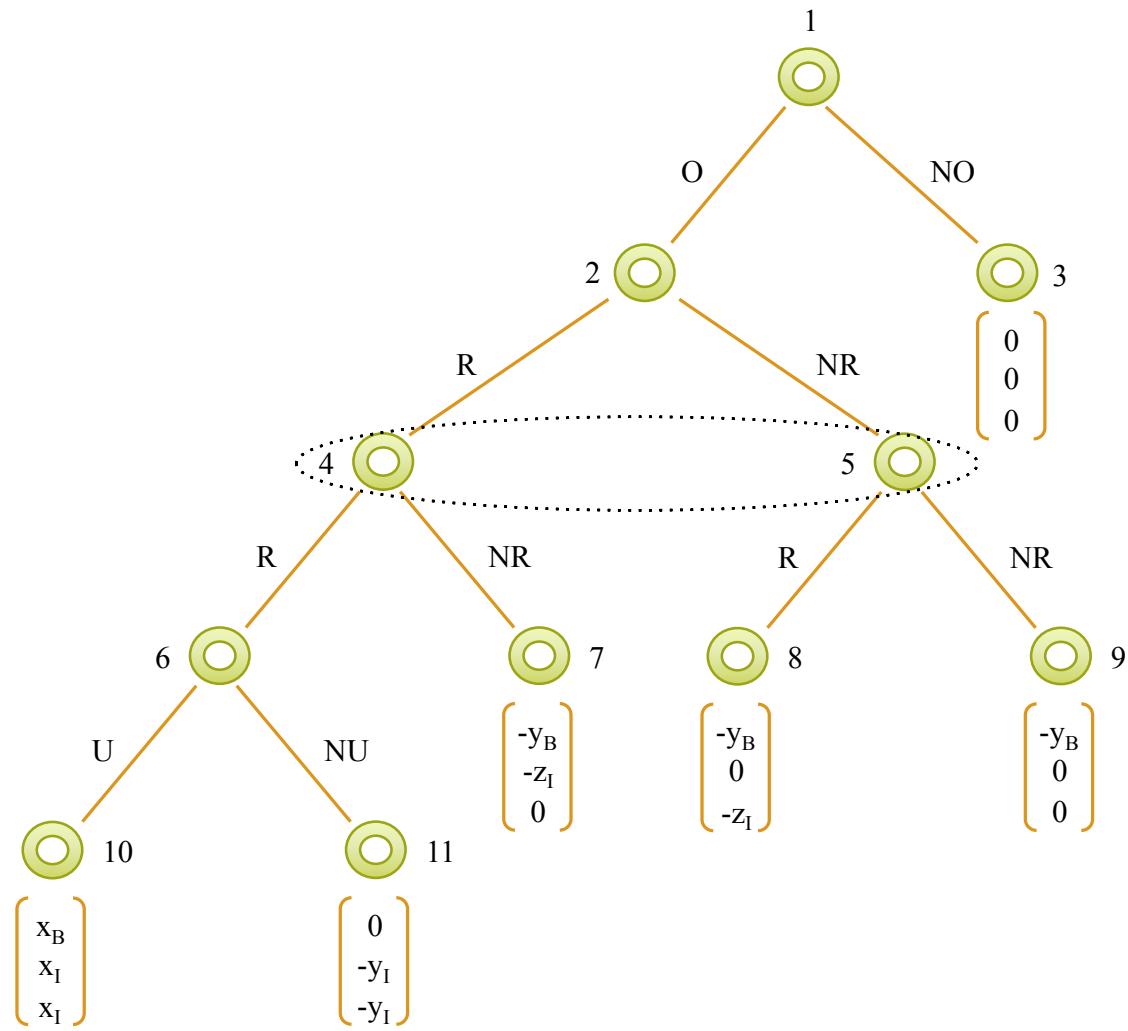


Figure 5
 “Normal Form Representation of the Coordination Game in the Repo Market” (Ennis 405)

		Investor 1	
		R	NR
		R	x_I, x_I
Investor 2	R	$-z_I, 0$	
	NR	$0, -z_I$	$0, 0$

Figure 6: Regression of perception of dealer and investor liquidity, expectations about economic growth, monetary policy, and MBS on BNYM's share of tri-party repo balances worldwide.

	TPR balances	TPR balances	TPR balances	TPR balances
VIX	0.008 (2.81)**	0.007 (2.59)*	0.005 (1.97)	0.011 (3.89)**
GDP	0.0002 (5.23)**	0.0002 (4.21)**	0.0003 (12.99)**	0.0003 (12.00)**
Yield	-0.027 (0.71)	-0.052 (1.12)	-0.031 (1.32)	0.019 (0.76)
Mortgage-related agency securities outstanding	-0.00000361 (0.36)			
All MBS and other guarantees outstanding held by third parties		-6.73e-08 (0.59)		
All maturities of MBS held by the Federal Reserve			-2.91e-07 (3.64)**	
All maturities of federal agency debt securities held by the Federal Reserve				-1.6e-07 (0.31)
Constant	-1.510 (3.02)**	-1.441 (2.64)*	-2.954 (8.59)**	-2.456 (6.50)**
R ²	0.83	0.83	0.91	0.88
Adjusted R ²	0.81	0.8	0.9	0.87
Observations	34	31	43	43

T-statistics are in the parentheses. * $p < 0.05$, ** $p < 0.01$