Dollar Illiquidity and Central Bank Facilities During the U.S. Sub-Prime Crisis

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Abstract

While the global financial crisis was centered in the United States, a global dollar shortage emerged at the height of the crisis that led to a surprising appreciation in the dollar exchange rate. In response, the Federal Reserve in cooperation with other central banks engaged in efforts to inject dollar liquidity into the international financial system. Empirical studies of the success of these efforts have yielded mixed results, in part because it is difficult to disentangle the effects of policy from those of news about the fundamentals at any point in time. In this paper, we develop a theoretical model of dollar illiquidity that yields cross-sectional predictions concerning the impact of central bank interventions that we will take to the data. We develop a two country model in which assets are valued for both their returns and their liquidity services. When the liquidity of one asset (toxic American mortgage-backed securities) declines, we show that the dollar appreciates as the demand for close substitutes increases in a ”flight to liquidity.” Moreover, the dollar asset injections conducted by central banks are predicted to have greater impacts in countries that are more exposed to the United States through trade and financial channels.

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1 Introduction

Although the recent crisis exposed fragilities throughout the global economy, there can be no doubt that it originated and was centered in the United States. When difficulties arose in sub-prime mortgages in early 2007, investors became concerned about a wide set of U.S. assets, resulting in fire sales. Banks responded to their asset losses by tightening their lending practices. The result was the failure or near-failure of a number of systemically important U.S. financial firms that triggered a broad sell-off of U.S. financial markets [Bernanke (2009)]. Between October 2007 and October 2008, there was a remarkable $8 trillion sell off in U.S. equity values [Brunnermeier (2009)].

However, a wholly unforeseen feature of the recent financial crisis is that the American dollar actually rose in value. Going into the crisis, most thought that one attribute of the adjustment process to undo the large global imbalances that had built up during the boom would be a sharp dollar depreciation [e.g. Krugman (2007)]. Instead, the crisis was unusual because the currency of the crisis country appreciated [Engel (2009)]. For example, see Figure 1, which plots the VIX and VSTOXX measures of US and European equity market volatility against the dollar-euro exchange rate at a daily frequency through the crisis period of late 2008. The dollar appreciation did not coincide with the financial woes that immediately followed the Lehman Brothers collapse of September 15, but began some two weeks later. Indeed, the exchange rate moved quite closely with volatility in equity markets, as can be seen by examining plots of the VIX and VSTOXX indices, market-based measures of equity market volatility in the United States and Europe respectively. The dollar appreciated almost in lock-step with the increased volatility in global financial markets. Further, the decline in volatility in global financial markets at the end of the year coincided with a decline in the value of the dollar.

Figure 1 leads us to the view that the appreciation of the dollar resulted from a flight to liquidity. There is a tight correlation between the American and European volatility indices measured by the VSTOXX. It seems unreasonable to ascribe the sharp appreciation of the dollar against the euro to a flight to safety; equities in both economies exhibit similar volatility throughout the crisis. Moreover, while it is probably true, as Fratzscher (2009) suggests, that there was an overall movement away from equities and towards securities, it is unclear that US securities should have been considered safer than their European counterparts, *especially since the crisis began in the United States!* Indeed, Cairns, Corinne, and McCauley (2007) find that the euro has tended historically to appreciate against the dollar during episodes of increased turbulence, suggesting that if anything, we would expect a flight to safety to result in a euro *appreciation* rather than a depreciation. Most existing empirical studies of the period [e.g. Baba and Packer (2009b)] characterize the illiquidity as a shortage in dollar funding suffered by financial institutions worldwide.

While the dollar appreciation may have reflected both a flight to safety and a flight to liquidity [e.g. McCauley and McGuire (2009)], we concentrate on the illiquidity issue here. We argue that viewed from the prism of a global dollar liquidity shortage due to the unique role still enjoyed by the dollar in global financial markets, the temporary appreciation of the dollar is unsurprising.[1]

The aggressive response taken by the Federal Reserve and other central banks suggests that officials also perceived the appreciation as reflective of a liquidity shortage. At the height of the crisis, the Federal Reserve extended dollar assets to major industrial countries, and several emerging markets' central banks to allow them to lend them to their domestic financial institutions

[1] The special role played by the dollar in goods invoicing is well-documented. Goldberg and Tille (2008) show that the dollar plays a prominent role in invoicing in international transactions, even in many that do not involve an agent from the United States. The motivation for the disproportionate propensity of goods to be invoiced in dollars has been studied extensively in the literature. Early studies emphasized invoicing choices based on reducing transactions costs [e.g. Swoboda (1968), while more recent studies have stressed mitigating exposure to macroeconomic volatility [Giovannini (1988), Goldberg and Tille (2009)] and network effects [e.g. Rey (2001) and Goldberg and Tille (2008)]. Similar concerns drive currency invoicing decisions in debt issuance and therefore the status of the dollar as a reserve currency [Chinn and Frankel (2007)]. Firms deciding whether to issue in domestic or foreign currency typically balance currency mismatch decisions, which favor issuing in domestic currencies to match domestic currency dominated revenue streams, against the transactions cost savings available from issuing in high volume currencies such as the dollar. A number of studies have used the advent of the euro to document the impact of scale effects on the currency issuance decision, as the volume of euro of issuance in euro immediately swamped issuance in any of the national currencies prior to the launch of the monetary union. Hale and Spiegel (2008) find that the probability that a non-financial firm would issue debt in euro was 35% higher after the launch of the EMU relative to issuance in pre-union national currencies, while Coeurdacier and Martin (2009) estimate that the advent of the euro reduced the cost of issuance by 14%-17%.

experiencing dollar shortages. In discussing the transactions, Obstfeld, Shambaugh, and Taylor (2009) note that desirable alternatives to the swap arrangements did not exist, as increased domestic currency extensions from local central banks could have led to undesirable currency depreciation, and the use of foreign central bank dollar reserves would have seriously reduced their holdings, leading to further anxiety about that country's prospects.[2] Obstfeld, Shambaugh, and Taylor (2009) claim that these transactions were "... one of the most notable examples of central bank cooperation in history ..." This underscores the severity of dollar illiquidity that was perceived to have existed at the height of the crisis.

The success of these liquidity injection efforts is more uncertain. In an early study, Taylor and Williams (2009) find no impact of these auctions on the 3-month spread of unsecured LIBOR lending rates over overnight index swaps (OIS), while McAndrews, Sarkar, and Wang (2008), who argued that a proper assessment of the impact of the TAF auctions required looking only at changes in the LIBOR-OIS spreads on days of announcements and auction operations do find an effect. Still, the magnitude of the effect is only estimated to be about 2 basis points per event date. Baba and Packer (2009b) examine disruptions in the FX swap market that began appearing at the height of the financial crisis. They find that the establishment of the international fund lines, as well as the dollar term funding auctions financed by these swaps significantly mitigated these disruptions after the Lehman crisis, but not before. Overall, then, it is safe to characterize the evidence on the impact of central bank interventions as mixed.

We reexamine the impact of the central bank policy responses in light of the surprising exchange rate appreciation exhibited by the dollar during the crisis. We develop a theoretical model in the following section that models the crisis as stemming from toxic American assets but still predicts a resulting dollar appreciation. We then use this model to derive cross-sectional predictions that can

[2] Unlike the transactions with the industrial country central banks, some of the swap arrangements with emerging market economies reflected the desire to provide liquidity to countries unwilling to obtain funds from the International Monetary Fund, and may have more reflected the need for hard currency reserves rather than the need for dollars [e.g. Engel (2009)].

be brought to the data to reassess the impact of the attempts by the Federal Reserve and others to inject dollar liquidity into the global financial system. We review a number of the relevant empirical regularities that have been found in the literature, and discuss how we incorporate our theoretical results into a specification that addresses some of the weaknesses that may have been responsible for the weak evidence on the impact of the central bank international activities to date. Finally, we provide some preliminary cross-sectional evidence on the impact of central bank efforts to inject liquidity into the global financial system during the recent crisis.

2 Theory

2.1 Overview

We derive a model to investigate the possibility that the liquidity advantages enjoyed by the dollar due to its "reserve currency" status played a role in its surprising resilience during the global financial crisis. We develop an international version of the search-based asset model of Lester, Postlewaite, and Wright (2009b), which is an extension of the well-known Lagos and Wright (2005) model. In this model, assets differ both in their returns and in their liquidity, and are valued based on both of these characteristics. The possibility of illiquidity arises because assets may be rejected by agents trading in decentralized markets. This is due to asset recognizability, which is endogenous. Agents must pay a fixed fee to acquire the ability to recognize an asset. In practice, some assets can become more recognizable than others, and therefore more liquid. Moreover, there is the potential for multiplicity of equilibria, as there are strategic complementarities across agents in the returns to investing in the capacity to recognize a given asset. In equilibrium, relative currency and asset values are functions of the probabilities that agents hold that they will encounter agents who will also be willing to accept those assets in the future, as in the international random-matching model of Matsuyama, Kiyotaki, and Matsui (1993).

Our model has two countries, the United States and the rest of the world. There are two assets in each country, currency and another asset which yields a fixed dividend like a Lucas tree, but is opaque. Agents must make a fixed investment to distinguish good from bad opaque assets. As in Lagos and Wright (2005), agents visit two markets each period: A centralized market, where all assets are admissible in trade and prices clear, and a decentralized market where agents are paired with another and engage in bilateral bargaining. Sellers in the decentralized market only accept assets denominated in their home currency, and of these only those that they are informed about and recognize. Agents in the centralized market choose a portfolio that they carry with them into the decentralized market, balancing the cost of carrying different types of assets against the expected cost of finding oneself liquidity-constrained in a bilateral meeting with a coincidence of wants. We assume that the probability of being paired with an agent from each country is proportional to the size of that country's economy.

We derive the equilibrium asset portfolios chosen by agents for a given steady state. We then examine the implications of a once and for all decline in the yield on the opaque US asset. Our results below show that agents respond to such a decline by reducing the value of that asset that they hold in their portfolio. This implies that in the event that they find themselves facing a coincidence of wants in a bilateral meeting with a US national, holding US dollar holdings constant, they will be more liquidity constrained. As a result, their demand for the other U.S. asset, in this case US currency, increases, raising its value relative to other assets, including the other national currency and hence resulting in an appreciation of the dollar exchange rate.

Broadly, we interpret the decline in the yield on the opaque asset as analogous to the fall in the perceived value of exotic US assets during the global financial crisis, and the appreciation of the dollar relative to the value of the other national currency as analogous to an increase in the relative yield of safe US assets. In this manner, our model yields the result observed in the data that a decline in the value of the opaque US asset can result in a dollar appreciation. The intuition behind this result is that the decline in the yield on the opaque US asset induces agents to carry less of that asset in their portfolios, reducing their dollar liquidity. This raises their demand for the liquidity services provided by US currency and raises the overall demand for US currency as well. When assets become illiquid, demand increases for assets that are substitutes for those assets in exchange. This would be particularly true for a "reserve currency," as one would expect that agents would have numerous liabilities outstanding that are denominated in that currency that would necessitate raising dollar liquidity to meet those obligations.

We do not want to suggest that the channel we model explicitly below was the only source of dollar illiquidity during the crisis. Brunnermeier (2009) discusses the "liquidity spirals" that resulted from declines in asset prices because of the influence of those asset price declines on bank balance sheet positions. During the crisis, the losses experienced by banks on their balance sheets led them to tighten their lending standards further. This led to fire sales and further reductions in liquidity. Emerging market countries also had a need for foreign currency reserves, as discussed above. We view the results here as complementary to these other potential sources of illiquidity, because they are all related to the exceptional role played by the dollar in world financial markets. We would not expect a similar paradoxical outcome for a non-reserve currency whose nation experienced a similar crisis.[3]

We follow Matsuyama, Kiyotaki, and Matsui (1993) in positing that the probability of meeting agents from one's own country in the decentralized market is also greater than that of being paired with an agent from the foreign country. This assumption yields a form of "home bias," as agents will to carry a greater share of their home assets into the decentralized market than we derive below in our benchmark case. Moreover, agents are more likely, holding al else equal, to become informed about their home opaque asset. Again, this extension is expected to increase the responsiveness of

[3]In our stylized model below, one would always get such a response. However, that result would certainly be overwhelmed in a richer model where there would be reduced demand for dollars because of the reduced demand for U.S. goods and assets.

asset holdings and the information choice to decreases in the yield on the opaque US asset.

Finally, our results are derived for a two-country model with two assets per country, but they can be easily extended to a larger set of countries. Because of the additivity of the utility function in the Lagos and Wright (2005) model, the only changes resulting from a decline in the yield on the opaque US asset is a decline in the value and liquidity of that asset, and an increase in the value and liquidity of US currency. The values of other country assets do not change, leaving the extension to a larger set of countries, such as the cross-section we examine in our empirical work, straightforward.

2.2 Illiquidity in search-based monetary models

It seems natural to turn towards the closed economy literature on money demand based on microeconomic frictions to examine the role of dollar illiquidity in its surprising appreciation during the recent crisis. Early studies, such as Kiyotaki and Wright (1993) established that a role for money that leads to positive money demand can be motivated within a search model where money acts as a convenient medium of exchange due to its superior liquidity, avoiding the need for a double coincidence of wants.[4] This analysis is extended in Trejos and Wright (1995), who incorporate bilateral bargaining to endogenize prices and derive monetary equilibria in a search-based model.

More recently, Lagos and Wright (2005) develop a model which allows for bargaining to take place in search-based monetary models in a very tractable manner. The vehicle to achieve this tractability is the addition of a decentralized market. Each period is divided into two sub-periods: In the first, agents enter a centralized market in which all goods and assets clear in a very standard manner. However, agents then move on to a decentralized market with anonymous bilateral matching and a double-coincidence problem reminiscent of the earlier search literature. The combi-

[4] Indeed, Kiyotaki and Wright (1993) argued long ago that such search-based models could be used for a wide variety of applications, beyond determining " ... which objects serve as media of exchange or to prove the existence of valued fiat money ..."

nation of these two markets allows for the incorporation of bargaining under interesting conditions, including the possibility of illiquidity, with tractability ensured by the fact that the next period all agents reunite in the centralized market where outcomes are degenerate and in particular do not depend on the distribution of money holdings across agents.

This useful methodology was extended further in Lester, Postlewaite, and Wright (2009b), who develop a closed-economy where assets differ in their general acceptability, and hence liquidity. In their model, assets may be of high or low quality, and agents that are uninformed refuse to accept low quality assets in exchange. Because agents reject outright any asset whose value is unrecognized, bargaining only takes place under full-information situations where equilibria are easily found. See Lester, Postlewaite, and Wright (2009a) for a demonstration that equilibria in which agents reject assets that they do not recognize at any price are feasible.

Given this simplifying assumption, Lester, Postlewaite, and Wright (2009b) are able to endogenize the agents' information decisions. Using this framework, the general acceptability of assets is shown to respond to changes in asset valuations and returns. In particular, an increase in the returns to an asset may lead to an increase in the probability of finding oneself in a desirable transaction with another agent who is carrying that asset, and thereby raise the expected gains from becoming capable of recognizing asset values. The model therefore raises the possibility of multiplicity of equilibria due to its strategic complementarities.

The tractable results found in Lester, Postlewaite, and Wright (2009b) are in part a function of the simplifying assumption that agents reject less-recognizable assets at any price, an assumption that we also adopt. The assumption is motivated by the assumption that valueless assets can be costlessly reproduced, while currencies are in fixed supply. This greatly simplifies the analysis, as bargaining only takes place under full-information situations where equilibria are easily found.[5]

[5] See Lester, Postlewaite, and Wright (2009a) for a demonstration that equilibria in which agents reject assets that they do not recognize at any price are feasible.

3 A two-country model with centralized and decentralized trading

3.1 Centralized market

There are two countries in the model, are labeled u and r, which can be interpreted as representing the United States and the rest of the world. To keep the analysis as simple as possible, we assume that their characteristics are identical, except where indicated. In particular, we assume that country z has an overall output share of $\tau_z; z = u, r$, where $0 \leq \tau_z \leq 1$ and $\tau_u = 1 - \tau_r$.

In each period in each country, a continuum of infinitely lived agents participate in two distinct international markets: One is a Walrasian centralized global market, and another is a decentralized market, where pairs of buyers and sellers from the two countries are randomly matched. Transactions in the decentralized market are characterized by a double-coincidence problem, which rules out barter, and anonymity, which rules out the provision of credit between matched agents. It therefore follows that a tangible medium of exchange is required for transactions to take place in the decentralized market.[6]

Preferences and production technologies are assumed to be identical across countries. On each date, agents from country z ($z = u, r$) can produce a tradable homogeneous good for the centralized market, x, using labor, h_z, according to the production function $x_z = h_z$. The law of one price holds in this market. Utility is assumed to be concave in x and negatively linear in h according to $U(x_z) - h_z$ and $U'(0) = \infty$, so that x_z^*, the optimal production of x in each country satisfies $U(x_z^*) = 1$.

Agents also produce a good, q_z, which is tradable in the international decentralized market. q_z is produced at disutility $c(q_z)$, where $c' > 0$, $c" > 0$, and $c(0) = c'(0) = 0$. Agents value q_z according to the concave function $\upsilon(q_z)$, where $\upsilon' > 0$, $\upsilon" < 0$, $\upsilon(0) = 0$, and $\upsilon'(0) = \infty$, so that

[6] These assumptions follow directly from Lagos and Wright (2005). As in that paper, the assumption of no barter and credit is stronger than necessary and only maintained for simplicity. It is not necessary that barter and credit are ruled out for all transactions, only a portion of them.

q_z^*, the optimal production of q_z satisfies $\upsilon'(q_z) = c'(q_z)$. To highlight the role that differences in information sets and asset illiquidity play in determining outcomes, we assume that both x and q are homogeneous across countries.

There are four assets in the model. Each economy has a domestic money supply, discussed in more detail below, as well as a real asset, which is like a Lucas tree. All agents have perfect information about the value of their economy's money, which is in fixed supply. The real assets yield a dividend in the centralized market the following period. There are good assets and bad assets. Bad assets yield a zero dividend, while good assets yield a dividend of δ_z units of x; $z = u, r$. Moreover, unlike money, bad assets can be produced by sellers at zero cost.

As in Lester, Postlewaite, and Wright (2009b), all agents can distinguish between bad and good assets in the centralized market, but in the decentralized market only informed agents, who have made a costly investment to be able to distinguish good assets from bad in that market can make this distinction.[7] Since bad assets can be produced at zero cost, sellers who do not know the value of an underlying asset will refuse to accept it at a positive price. This yields the simplification that bargaining only takes place under situations where both agents are informed, which are relatively tractable to solve. Finally, note that money can have value, although it also yields zero dividends, because it is in fixed supply and provides liquidity services. Let ϕ_z and ψ_z represent the values of money and real assets of country z ($z = u, r$) in the centralized market in terms of x respectively.

We focus on steady state equilibria. There is a fixed supply of trees in each country, A_z, and the supplies of both currencies grow at a constant rate, γ_z. Let $\widehat{k}$ represent the next period value of any variable k, so that $\widehat{M_z} = \gamma_z M_z$. Agents worldwide are assumed to share a common discount factor, β, and we assume that $\gamma_z > \beta$ for both countries.

It has been shown [e.g. Lagos and Rocheteau (2008)] that agents may choose to keep some of

[7]Lester, Postlewaite, and Wright (2009b) argue that one intuition consistent with this setup is that there are third parties in the centralized market that identify good and bad assets and others can simply mimic their valuations.

their assets out of the bargaining process in the decentralized market if they are allowed to do so, as the endowments of each agent can affect the bargaining outcome. This would be true in our model as well. However, to accommodate assets from two countries without too much complexity, we make the simplifying assumption that all assets owned by agents are brought into the decentralized market. We also assume that assets are "scarce," and therefore carry a liquidity value over their value in exchange the following day in the centralized market. We derive the conditions for asset scarcity below.

Agents from country z ($z = u, r$) choose a portfolio comprised of four assets: $m_{z,u}$ units of country u currency, $m_{z,r}$ units of country r currency, $a_{z,u}$ units of country u real assets, and $a_{z,r}$ units of country r assets. Let y_z represent income of an agent from country z in the centralized market, which satisfies

$$y_z = \phi_u m_{z,u} + \phi_r m_{z,r} + (\delta_u + \psi_r) a_{z,u} + (\delta_r + \psi_r) a_{z,r}. \tag{1}$$

Let $W(y_r)$ be the value function of an agent from country z in the centralized market. Moreover, define $V_z(m_{z,u}, m_{z,r}, a_{z,u}, a_{z,r})$ as the value function of an agent from country z in the decentralized market with portfolio $(m_{z,u}, m_{z,r}, a_{z,u}, a_{z,r})$. The optimization problem in the centralized market for an agent from country z then satisfies

$$\max_{x_z, h_z, \widehat{m}_{z,u}, \widehat{m}_{z,r}, \widehat{a}_{z,u}, \widehat{a}_{z,r}} W(y_z) = \{U(x_z) - h_z + \beta V_{z,u}(\widehat{m}_{z,u}, \widehat{m}_{z,r}, \widehat{a}_{z,u}, \widehat{a}_{z,r})\} \tag{2}$$

subject to

$$x_z \leq h_z + y_z - \phi_u \widehat{m}_{z,u} - \phi_r \widehat{m}_{z,r} - \psi_u(\widehat{a}_{z,u}) - \psi_r(\widehat{a}_{z,r}) + T_z, \tag{3}$$

where T_z is a lump-sum transfer returned to private agents in country z from revenues generated by money creation, $T_z = (\gamma_z - 1)M_z$. Finally, we assume that $\gamma_z > 1$ and as in Lagos and Wright (2005), we assume that any constraints on h_z, $h_z \epsilon \overline{h}$ are not binding.

Agents' first order conditions satisfy

$$U'(x_z) = 1, \tag{4}$$

$$\phi_u \geq \beta \frac{\partial V_z}{\partial \widehat{m}_{z,u}}, \tag{5}$$

$$\phi_r \geq \beta \frac{\partial V_z}{\partial \widehat{m}_{z,r}}, \tag{6}$$

$$\psi_u \geq \beta \frac{\partial V_z}{\partial \widehat{a}_{z,u}}, \tag{7}$$

and

$$\psi_r \geq \beta \frac{\partial V_z}{\partial \widehat{a}_{z,r}}. \tag{8}$$

where the latter four conditions hold with equality when $m_{z,u}$, $m_{z,r}$, $a_{z,u}$, and $a_{z,r}$ are strictly positive, respectively. Note that y_z does not enter into the first order conditions and $W'(y_z) = 1$. This is the mechanism through which the degenerate portfolio solutions are recovered each time the agents return to the centralized market in the Lagos and Wright (2005) framework.

Finally, there are four asset market clearing conditions, as the representative agent from each country holds his country's share of each asset:

$$M_u = m_{u,u} + m_{r,u}, \tag{9}$$

$$M_r = m_{u,r} + m_{r,r}, \tag{10}$$

$$A_u = a_{u,u} + a_{u,r}, \tag{11}$$

and

$$A_r = a_{u,r} + a_{r,r}. \tag{12}$$

3.2 Decentralized market

We next turn to the equilibrium in the decentralized market. In the decentralized market, agents are randomly paired into bilateral meetings. Let z and k represent the countries of origin of the buyer and seller respectively in the decentralized market $z, k = i, j$. Buyers can be paired with sellers from their own country $z = k$, or with sellers from the foreign country $z \neq k$. To highlight the possibility of liquidity differences arising across countries, we assume that sellers in the decentralized market only accept assets denominated in their domestic currencies in exchange.[8]

We assume that the probability of landing in a meeting in which there is a coincidence of wants is exogenous, although we allow the probability of landing in meeting with a coincidence of wants to vary by nationality. We assume that there are two arguments to the probability of an agent from country z ($z = u, r$) being paired with an agent from country k ($k = u, r$) with a coincidence of

[8]This assumption is made for tractability. In practice, the qualitative results would go through with assets from the other country being subject to increased transactions costs. This assumption serves to simplify the decision rule, as we only need to consider two types of agents from each country, informed and uninformed.

wants. First, we assume that the probabilities of being paired with an agent from country k from whom you wish to buy or sell are proportional to the share of output of country k, τ_k. Second, we assume that the probability of a coincidence of wants is greater among agents originating from the same country. We assume that the probability of a coincidence of wants between two agents from the same country exceeds that of two agents from different countries by an exogenous parameter α, where $\alpha > 1$.

Specifically, let $\lambda_{z,k}$ represent the chance of an agent from country z being paired with an agent from country k from whom he would want to buy, and $\widetilde{\lambda}_{z,k}$ represent the chance of an agent from country z being paired in a meeting with an agent from country k to whom he wants to sell. We assume that $\lambda_{z,k} \equiv \lambda\tau_k$ when $z \neq k$ and $\lambda_{z,k} \equiv \lambda\alpha\tau_k$ when $z = k$, where λ is an exogenous constant term. Similarly, we assume that $\widetilde{\lambda}_{z,k} \equiv \widetilde{\lambda}\tau_k$ when $z \neq k$ and $\widetilde{\lambda}_{z,k} \equiv \widetilde{\lambda}\alpha\tau_k$ when $z = k$, where $\widetilde{\lambda}$ is an exogenous constant term.

Outcomes in the decentralized market are a function of the portfolio of assets held by the buyer as well as the seller's information set. We assume that all agents from country k are fully informed about the value of their domestic currency, m_k $(k = u, r)$. However, we assume that only a fraction of agents in country k, ρ_k, are informed about the value of asset a_k, where $0 \leq \rho_k \leq 1$. ρ_k is therefore also the probability that a randomly selected seller from k is willing to accept both m_k and a_k in transactions, while $1 - \rho_k$ represents the probability that a seller from country k is uninformed about the value of a_k and is only willing to accept m_k as payment. As in Lester, Postlewaite, and Wright (2009b), let meetings where the seller is informed about a_k be called "type 2," and meetings where the seller is uninformed be called "type 1." The type of meeting that is taking place is known to all.

We next examine the characteristics of a type n meeting $(n = 1, 2)$ where there is a coincidence of wants between a buyer from country z and a seller from country k. Let $p_{z,k,n}$ represent the price paid by the buyer from country z to a seller from country k for $q_{z,k,n}$ units of the good in a type

n meeting. Let $(m_{z,u}, m_{z,r}, a_{z,u}, a_{z,r})$ represent the buyer's portfolio, and $(\widetilde{m}_{k,u}, \widetilde{m}_{k,r}, \widetilde{a}_{k,u}, \widetilde{a}_{k,r})$ represent the seller's portfolio, and y_z and y_k represent the wealth of the buyer and the seller respectively. Finally, let $\omega_{z,k,n}$ be the value of acceptable funds possessed by the buyer, i.e. those recognized by the seller. Given our assumptions above, $\omega_{z,k,1} = \phi_k m_{z,k}$, and $\omega_{z,k,2} = \phi_k m_{z,k} + (\psi_k + \delta_k) a_{z,k}$.

Assuming that the buyer has bargaining power θ and threat points are given by continuation values, the generalized Nash bargaining solution is similar to that in Lagos and Wright (2005):[9]

$$\max_{q_{z,k,n}, p_{z,k,n}} [[\upsilon(q_{z,k,n}) + W(y_z - p_{z,k,n})] - W_z(y_z)]^{\theta} [[-c(q_{z,k,n}) + W(y_k + p_{z,k,n})] - W(y_k)]^{1-\theta} \quad (13)$$

subject to $p_{z,k,n} \leq \omega_{z,k,n}$.

The first order conditions satisfy

$$p_{z,k,n} = \frac{\theta \upsilon'(q_{z,k,n}) c(q_{z,k,n}) + (1-\theta) \upsilon(q_{z,k,n}) c'(q_{z,k,n})}{\theta \upsilon'(q_{z,k,n}) + (1-\theta) c'(q_{z,k,n})} \equiv \eta(q_{z,k,n}), \quad (14)$$

and

$$-\theta[-c(q_{z,k,n}) + p_{z,k,n}] + (1-\theta)[\upsilon(q_{z,k,n}) - p_{z,k,n}] - \varphi[-c(q_{z,k,n}) + p_{z,k,n}]^{\theta} [\upsilon(q_{z,k,n}) - p_{z,k,n}]^{(1-\theta)} = 0. \quad (15)$$

There are two cases, depending on whether the buyer's liquidity constraint is binding. First, if the constraint is not binding, then $q_{z,k,n} = q^*$, which satisfies $\upsilon'(q^*) = c'(q^*)$. It also follows

[9]The generalized bargaining solution is based on the assumption that the alternative to the bargaining outcome is autarky. We give buyers from either country identical bargaining power, θ, for simplicity. This drives none of our results, and indeed, it is unclear why we would think that buyers from either country should hold a bargaining advantage over the other unrelated to the differences in asset liquidity which are explicitly modeled here.

that $p_{z,k,n} = \eta(q^*)$, which satisfies 14. However, if the liquidity constraint is binding we are in an illiquid situation, where $p_{z,k,n} = \omega_{z,k,n}$ and $q_{z,k,n}$ satisfies 14 for $p_{z,k,n} = \omega_{z,k,n}$. Note that in either case the terms of trade only depend on the buyer's portfolio, and not that of the seller, although the type of meeting, n, depends on the seller's information set.

The value function of an agent from country z in the decentralized market is then equal to the probabilities of being a buyer in a type 1 or 2 meeting with a seller from county k, times the payoffs in those meetings, plus the probability of being either a seller or in a meeting with no opportunity for trade, plus a constant term, Ψ_z.

$$V_z = \sum_{n=1}^{2} [\lambda_{i,n}[\upsilon(q_{z,i,n}) + W(y_z - p_{z,i,n})] + \lambda_{j,n}[\upsilon(q_{z,j,n}) + W(y_z - p_{z,j,n})]] + (1-\lambda)W(y_z) + \Psi_k \quad (16)$$

where $\lambda_{k,1} = \lambda_k(1-\rho_k), \lambda_{k,2} = \lambda_k \rho_k, k = i, j$, and Ψ_k represents the extra utility of an agent from country k associated with being a seller relative to having no trade opportunities.

To solve for Ψ_k, let $\widetilde{q}_{z,k,n}$ and $\widetilde{p}_{z,k,n}$ represent the volume of q sold to an agent from country z ($z = 1, 2$), and the proceeds of the sale respectively. Ψ_k satisfies

$$\Psi_k = \{\widetilde{\lambda}_i[-c(\widetilde{q}_{i,k,1}) + \widetilde{p}_{i,k,1}] + \widetilde{\lambda}_j[-c(\widetilde{q}_{j,k,1}) + \widetilde{p}_{j,k,1}]\}(1-\Phi_k) + \{\widetilde{\lambda}_i[-c(\widetilde{q}_{i,k,2}) + \widetilde{p}_{i,k,2}] + \widetilde{\lambda}_j[-c(\widetilde{q}_{j,k,2}) + \widetilde{p}_{j,k,2}]\}\Phi_k \quad (17)$$

where Φ_k is an indicator variable that takes value 1 if agent k is informed about a_k, and 0 otherwise.

It can be easily seen that Ψ_k is invariant to the portfolio decision of the agent from country k, as it is only a function of the portfolio of the buyer, and taken as given. However, it can also be seen that Ψ_k depends on whether or not the agent is informed, which enters into the information decision below.

It is useful to follow Lagos and Wright (2005) in defining a function $\ell(q_{z,k,n})$ as the liquidity premium prevailing in a type n meeting with a buyer from country z and a seller from country k. This function represents the increase in the buyer's utility from bringing an additional unit of wealth into the type n meeting over and above the value of just bringing that extra unit of wealth into the next centralized market. $\ell(q_{z,k,n})$ satisfies

$$\ell(q_{z,k,n}) \equiv \frac{\upsilon'(q_{z,k,n})}{\eta'(q_{z,k,n})} - 1. \tag{18}$$

Note that $\ell(q_{z,k,n})$ is only a function of buyer characteristics. Moreover, we also follow Lagos and Wright (2005) in assuming that $\ell'(q_{z,k,n}) \leq 0$, which holds under usual conditions.

Differentiating V_z, the first order conditions for money demand satisfy

$$\frac{\partial V_z}{\partial m_{z,i}} = \phi_i[\lambda_{i,1}\ell(q_{z,i,1})I\{\omega_{z,i,1} < \eta(q^*)\} + \lambda_{i,2}\ell(q_{z,i,2})I\{\omega_{z,i,2} < \eta(q^*)\} + 1] \tag{19}$$

and

$$\frac{\partial V_z}{\partial m_{z,j}} = \phi_j[\lambda_{z,j,1}\ell(q_{z,j,1})I\{\omega_{z,j,1} < \eta(q^*)\} + \lambda_{j,2}\ell(q_{z,j,2})I\{\omega_{z,j,2} < \eta(q^*)\} + 1]. \tag{20}$$

The first order conditions for asset demand satisfy

$$\frac{\partial V_z}{\partial a_{z,i}} = (\psi_i + \delta_i)[\lambda_{i,2}\ell(q_{z,i,2})I\{\omega_{z,i,2} < \eta(q^*)\} + 1] \tag{21}$$

and

$$\frac{\partial V_z}{\partial a_{z,j}} = (\psi_j + \delta_j)[\lambda_{j,2}\ell(q_{z,j,2})I\{\omega_{z,j,2} < \eta(q^*)\} + 1]. \tag{22}$$

Combining 19, 20, 21, and 22 with the centralized market solution conditions, we obtain solutions for the conditions determining portfolio demand. The demand for currency i satisfies

$$\phi_i \geq \beta\widehat{\phi}_i[\lambda_{i,1}\ell(\widehat{q}_{z,i,1})I\{\widehat{\omega}_{z,i,1} < \eta(q^*)\} + \lambda_{i,2}\ell(\widehat{q}_{z,i,2})I\{\widehat{\omega}_{z,i,2} < \eta(q^*)\} + 1], \tag{23}$$

while the demand for currency j satisfies

$$\phi_j \geq \beta\widehat{\phi}_j[\lambda_{j,1}\ell(\widehat{q}_{z,j,1})I\{\widehat{\omega}_{z,j,1} < \eta(q^*)\} + \lambda_{j,2}\ell(\widehat{q}_{z,j,2})I\{\widehat{\omega}_{z,j,2} < \eta(q^*)\} + 1], \tag{24}$$

where the conditions hold with equality if $\widehat{m_i}$ and $\widehat{m_j}$ are strictly positive, respectively.

The demand for assets satisfy

$$\psi_i \geq \beta(\widehat{\psi}_i + \delta_i)[\lambda_{i,2}\ell(\widehat{q}_{z,i,2})I\{\widehat{\omega}_{z,i,2} < \eta(q^*)\} + 1], \tag{25}$$

and

$$\psi_j \geq \beta(\widehat{\psi}_j + \delta_j)[\lambda_{j,2}\ell(\widehat{q}_{z,j,2})I\{\widehat{\omega}_{z,j,2} < \eta(q^*)\} + 1], \tag{26}$$

where the conditions again hold with equality if $\widehat{a_i}$ and $\widehat{a_j}$ are strictly positive, respectively.

3.3 Equilibrium

We first solve for the equilibrium for given values of $\rho_k; k = i, j$, and then solve for the information decisions. Equilibrium is defined as a solution for asset holdings by agents from i and j, $(m_{i,i}, m_{i,j}, a_{i,i}, a_{i,j})$, and $(m_{j,i}, m_{j,j}, a_{j,i}, a_{j,j})$, asset prices $(\phi_i, \phi_j, \psi_i, \psi_j)$, the terms of trade in the decentralized markets, $(p_k, q_k); k = i, j$, and the leisure choices, (x_i, h_i) and (x_j, h_j), which satisfy the maximization conditions of each agent, the bargaining solutions in the decentralized markets, and market clearing in the centralized market.

In the steady state equilibrium, real variables are constant over time, so that $q_z = \widehat{q_z}$, $\phi_z m_z$ and $\psi_z a_z$ are constant, and ϕ_z and M_z grow at a constant rate γ_z $(z = i, j)$. The steady state versions of money demand equations 27 and 28 satisfy

$$\frac{\gamma - \beta}{\beta \lambda_i} \geq (1 - \rho_i)\ell(q_{z,i,1}) I\{\widehat{\omega}_{z,i,1} < \eta(q^*)\} + \rho_i \ell(q_{i,2}) I\{\widehat{\omega}_{z,i,2} < \eta(q^*)\}, \tag{27}$$

while the demand for currency j satisfies

$$\frac{\gamma - \beta}{\beta \lambda_j} \geq (1 - \rho_j)\ell(q_{z,j,1}) I\{\widehat{\omega}_{z,j,1} < \eta(q^*)\} + \rho_j \ell(q_{j,2}) I\{\widehat{\omega}_{z,j,2} < \eta(q^*)\}, \tag{28}$$

where the conditions hold with equality for agents that hold strictly positive levels of m_i and m_j respectively.

The demand for assets satisfy

$$\frac{(1 - \beta)\psi_i - \beta \delta_i}{\beta(\psi_i + \delta_i)\lambda_i} = \rho_i \ell(q_{z,i,2}) I\{\omega_{z,i,2} < \eta(q^*)\}, \tag{29}$$

and

$$\frac{(1 - \beta)\psi_j - \beta \delta_j}{\beta(\psi_j + \delta_j)\lambda_j} = \rho_j \ell(q_{z,j,2}) I\{\omega_{z,j,2} < \eta(q^*)\}, \tag{30}$$

where the conditions hold with equality for agents that hold strictly positive levels of a_i and a_j respectively.

The equilibrium solution is described as the following proposition:

Proposition 1 *There exists a unique steady state monetary equilibrium for which* ($q_{z,i,1}$ *and* $q_{z,i,2}$ *satisfy 27 and 29,* ($q_{z,j,1}$) *and* ($q_{z,j,2}$) *satisfy 28 and 30, prices satisfy* $\phi_k = \eta(q_{z,k,1})/M_{z,k}$ *and* $\psi_k = [\eta(q_{z,k,2} - \eta(q_{z,k,1}]/A_{z,k} - \delta_k$ *where* $(z, k = i, j)$.

The proof is in the appendix.

3.4 Comparative statics

Given the equilibrium, we next examine the comparative static impact of a decline in δ_i. First by equation 29, the change in ψ_i with a decline in δ_i satisfies

$$\frac{\partial\psi_i}{\partial\delta_i} = \frac{\delta_i - \beta(\psi_i + \delta_i)\lambda_i\rho_i\ell'(q_{z,i,2})I\{\omega_{z,i,2} < \eta(q^*)\}}{\psi_i - \beta(\psi_i + \delta_i)\lambda_i\rho_i\ell'(q_{z,i,2})I\{\omega_{z,i,2} < \eta(q^*)\}}. \tag{31}$$

The numerator of equation 31 is unambiguously positive, but the denominator is ambiguous in sign. The necessary condition for $\partial\psi_i/\partial\delta_i \geq 0$ is that $\ell'(q_{z,i,2})$ is not "too large". We require

$$\psi_i \geq \beta(\psi_i + \delta_i)\lambda_i\rho_i\ell'(q_{z,i,2})I\{\omega_{z,i,2} < \eta(q^*)\}. \tag{32}$$

It seems implausible that the value of an asset could rise with a permanent decline in its dividend stream, which is the possibility that necessitates the condition above. However, the fact that we have utility that is additive in consumption of goods from the centralized and decentralized markets implies that it is possible that the demand for the good exchanged in the decentralized market is so inelastic that the decline in δ_i leads to a surge in the value of the liquidity services of asset a_i that its price actually increases. This would be the case, for example, if the demand for good q was completely inelastic. The above condition merely constrains $\ell'(q_{z,i,2})$ to not be large enough for this unlikely outcome. Given satisfaction of this condition, it follows that $\partial\psi_i/\partial\delta_i \geq 0$.

In contrast, it can be seen by inspection of equation 30 ψ_j is invariant to a decline in δ_i.

Substituting from equation 29 into equation 27 we obtain

$$\gamma - \beta \geq \beta\lambda_i(1-\rho_i)\ell(q_{z,i,1})I\{\widehat{\omega}_{z,i,1} < \eta(q^*)\} + \frac{\psi_i}{(\psi_i + \delta_i)}. \tag{33}$$

In the steady the level of real balances taken by an agent from country z into the decentralized market, $\phi_i m_{z,i}$, will be a constant. However, the steady state value of $\phi_i m_{z,i}$ will be endogenous, and in particular a function δ_i. Totally differentiating with respect to $\phi_i m_{z,i}$ and δ_i yields

$$\frac{\partial \phi_i m_{z,i}}{\partial \delta_i} = \frac{\psi_i + \delta_i \frac{\partial \psi_i}{\partial \delta_i}}{(\psi_i + \delta_i)^2 \beta\lambda_i(1-\rho_i)\ell'(q_{z,i,1})I\{\widehat{\omega}_{z,i,1} < \eta(q^*)\}} \leq 0, \tag{34}$$

as $\frac{\partial \psi_i}{\partial \delta_i}$ can be signed as positive given satisfaction of condition 32.

Again, in contrast, it can be seen by inspection of equation 28, combined with the fact that ψ_j is invariant to a decline in δ_i, that $\phi_j m_{z,j}$ will be invariant to a change in δ_i. This leads to our second proposition:

Proposition 2 *A decline in the payment stream of the risky asset from country i will lead to an appreciation in country i's exchange rate,* ϕ_i/ϕ_j.

The proof follows directly from equation 34. As $m_{z,i}$ is exogenous, the change in real balances, $\phi_i m_{z,i}$ must come from an increase in ϕ_i. Similarly, since $m_{z,j}$ is exogenous and there is no change in $\phi_j m_{z,j}$, it follows that ϕ_j is unchanged. Therefore, ϕ_i/ϕ_j, the exchange rate between the currencies of the two countries, must have risen.

The intuition behind Proposition 2 is that the fall in δ_i reduces the value of assets that the agent brings into a type 2 meeting, raising the value of liquidity services of country i assets brought into that meeting. In particular, it also raises the value of liquidity services provided by country i currency. As the stock of money is constant, the portfolio is brought back into equilibrium through an increase in the price of country i currency, ϕ_i. This raises real balances brought into type 1 meetings with sellers from country i, and reduces the marginal liquidity services of country i currency back to a level that restores equilibrium.

4 Empirics

4.1 Exposure to American Assets: Menace or Aid?

What effect does the surprising performance of the dollar have? We studied that recently in Rose and Spiegel (2009b), where we explored the linkages between manifestations of the 2008 financial crisis and financial exposure to the United States. We built an empirical model that linked four different manifestations of the 2008 crisis to a number of different potential causes of the crisis. We found that countries which were more heavily exposed to American assets did not do worse, even though one might think that toxic American assets were the root causes of the crisis. Instead, countries with greater American exposure had more shallow crises, perhaps because declines in American financial markets were partially offset by the American appreciation.[10] Of course, not all U.S. assets performed uniformly. While asset-backed securities related to U.S. real estate lost value during the crisis, the value of U.S. Treasury bonds rose.

Table 1 reports the coefficient estimates from a specification in which the impact of exposure to the United States affects the severity of a country's crisis. This is estimated for a large cross section of countries on a latent variable estimate of relative performance during the global financial crisis.[11] The first row reports the coefficient estimate on the share of external assets originating from the United States, as measured by the 2006 IMF CPIS data set. It can be seen that the coefficient

[10] See Rose and Spiegel (2009a) for derivation of the country characteristic base specification.

[11] Estimation is done using the MIMIC (multiple indicator-multiple cause) model. Relative performance during the crisis is measured in terms of relative performance according to four "manifestation variables," including changes in real GDP, the stock market, the national credit rating, and the exchange rate. See Rose and Spiegel (2009a) and Rose and Spiegel (2009b) for details concerning the econometric methodology used in the study.

estimate on holdings of U.S. assets is positive and significantly different from zero at a 5% confidence level. The remainder of Table 1 reports the impact of exposure for smaller classes of U.S. assets, including the CPIS debt shares, the CPIS long-term debt shares, the BIS consolidated banking shares, and *Treasury International Capital* (TIC) system data for holdings of a number of subsets of U.S. assets as a share of gross domestic product.[12] Finally, we include the share of holdings of publicly guaranteed debt that is denominated in dollars, taken from the World Bank *Global Development Finance* data set. While the results are mixed in terms of statistical significance, the bulk of exposure measures tend to come in positively, with significance more prevalent for measures that would be more closely associated with holdings of safe assets, such as U.S. Treasuries.

4.2 Central Bank Responses to Dollar Illiquidity

Central bank swap lines were first extended in December 2007. The size of the swap lines and the number of countries involved in swaps changed markedly over the course of the crisis. Initially, the Federal Reserve established temporary reciprocal currency arrangements with the European Central Bank (ECB) and the Swiss National Bank allowing for the drawing of $20 billion and $4 billion respectively. However, as growing numbers of foreign banks exhibited liqudiity shortages, the programs were expanded. By October of 2008, the program became "uncapped" for the ECB, the SNB, the Bank of Japan (BOJ), and the Bank of England (BOE).[13] These swap lines allowed these foreign central banks to access dollar-denominated assets which they could then lend to their financial institutions that were experiencing dollar illiquidity. At the height of the program at the end of 2008, draw downs reached $291 billion at the ECB, $122 billion at the BOJ, and $45 billion at the Bank of England [Goldberg, Kennedy, and Miu (2010)].

Other central bank efforts to inject dollar liquidity also emerged. The term auction facility

[12] As we only have this data for U.S. exposure, we normalize by GDP. For example, U.K. holdings of U.S. assets are expressed as a share of U.K. GDP.

[13] See Goldberg, Kennedy, and Miu (2010) for a review of the details of the central bank swap programs during the crisis.

(TAF) program, aimed at providing funds to financial institutions, was also introduced in December of 2007. Through this facility, depository iinstitutions were able to borrow directly from the Federal Reserve without using the discount window [Taylor and Williams (2009)].[14] The ECB also conducted dollar term funding auctions. These were supported by the swap lines with the Federal Reserve and provided dollar funds to institutions in the European Union with ECB-eligible collateral [Baba and Packer (2009a)].

As financial conditions improved, the terms offered under the overseas swap facilities became less desirable. Offer rates for dollar swap facility funds reached about 100 basis points higher than terms available to US and some foreign financial institutions under the TAF program. Moreover, by the first quarter of 2009 the market terms had improved to the point that participation in central bank swaps would only have been attractive to institutions lacking access to funds in private markets or lacking collateral necessary to participate in the TAF program [Goldberg, Kennedy, and Miu (2010). Nevertheless, participation in the TAF program remained widespread.

The swap arrangements were designed to address exceptional circumstances, and it is not surprising that draw downs decreased rapidly as financial conditions improved. Still, at their peak they represented a crucial part of efforts by global officials to restore liquidity to the financial system, as evidenced by the enormous draw downs at the end of 2008 reported above. In response, a number of studies have emerged attempting to gauge the success of the programs in improving global dollar liquidity.

In an early study, Taylor and Williams (2009) examine the impact of the TAF auctions. They find no impact of these auctions on the 3-month spread of unsecured LIBOR lending rates over overnight index swaps (OIS), which they take as a proxy for interest rate expectations. There work was followed by a number of researchers, including McAndrews, Sarkar, and Wang (2008),

[14] As Taylor and Williams (2009) point out, it is important to remember that the liquidity effects of the TAF auctions is not due to any increase in total bank reserves of the amount of "high-powered money" in the financial system, as bank borrowing from the Fed was offset by open market sales of securities.

who argued that a proper assessment of the impact of the TAF auctions required looking only at changes in the LIBOR-OIS spreads on days of announcements and auction operations. Using this methodology, they find that the TAF auctions and announcements accounted a cumulative reduction of more than 50 basis points in the OIS-LIBOR spread. Moreover, they find that international TAF auctions also had a statistically significant and even larger impact on spreads than domestic auctions. Interestingly, both McAndrews, Sarkar, and Wang (2008) and subsequent work by Taylor and Williams (2008) based on spreads find that announcements had larger impacts on spreads than actual auctions.

Other efforts to characterize the impact of the central bank dollar injections concentrate on evidence from the FX swap market. As discussed in Baba and Packer (2009b), disruptions in the FX swap market began appearing at the height of the financial crisis. FX swap prices began to reflect increases in perceived counterparty risk among European financial institutions, as doubts grew about the abilities of these institutions to fulfill their dollar obligations. This resulted in deviations from short-term covered interest parity. Baba and Packer (2009b) find that the establishment of the international fund lines, as well as the dollar term funding auctions financed by these swaps had a significant downward impact on observed deviations from covered interest parity in the FX swap market. They obtain mixed results, as US dollar auctions are found to have had a robust negative impact on deviations to covered interest parity, subsequent to the Lehman failure, but not before. Similar results are reported in Baba and Packer (2009a).

The impact of the central bank actions on a broader set of countries is examined by Aizenman and Pasricha (2010). They concentrate on emerging market economies that were granted swap arrangements by the Federal Reserve at the height of the crisis. They find that the set of emerging market economies that received swap arrangements were selected in part on the basis of having exceptionally large outstanding obligations to the Federal Reserve. They find that the establishment of swap arrangements had little impact on national credit default swap spreads, but did contribute to exchange rate appreciation, or at least stemmed the depreciation of the exchange rate.

Overall, then, it is safe to characterize the evidence on the impact of central bank interventions as mixed. Even the work of McAndrews, Sarkar, and Wang (2008), which was subsequently confirmed by Taylor and Williams (2008), only finds about a 2 basis point impact of TAF events on LIBOR-OIS spreads. While it may not be surprising that the dollar auctions had their greatest effect during the height of turmoil, it is safe to say that the observed responses during the pre-Lehman period was disappointing. Indeed, it was during this period that the unprecedented policies were adopted, providing a reminder that while this period was not turbulent relative to what immediately followed, it was still exceptional relative to recent historical data.

A number of difficulties have been pointed out with the time series-based evidence discussed in this section. One problem is that these approaches implicitly ascribe all movements not covered by measured changes in counterparty risk to the policy action [Taylor and Williams (2009)]. Another is that there is clear evidence that central bank swap policies have been endogenous: Aizenman and Pasricha (2010) find that the set of emerging market economies chosen as candidates for swap arrangements are notable in the magnitude of their outstanding US debt obligations. Similarly, one would think that private agents would consider an announcement concerning the design of the international swap program as revealing something about the central banks' views about the severity of the crisis situation. The time series evidence above has difficulty separating the direct impact of the program from its impact through private sector expectations.

For these reasons, combined with the mixed results discussed above, it would be desirable to identify restrictions that one could make in the cross-section to take to the data to identify the impact of the central bank actions. That would allow one to identify a single policy intervention, and then examine the relative impact across a cross-section of countries to this single event. This avoids a number of the timing and endogeneity issues discussed above. This is the path we intend to take in our empirical work.

4.3 Sketch of empirical work

We propose to utilize the theory discussed below to identify restrictions in the cross section that can be taken to the data. Our model suggests that holding all else equal, a nation that has larger exposure to the United States in trade is likely to be more sensitive to central bank dollar liquidity injections than one with less exposure. Similarly, Peter and McGuire (2009) argue that differences in financial system balance sheet exposure to US assets are likely to be positively correlated with dollar shortage vulnerabilities and hence also more sensitive to central bank actions. We therefore propose to use the information available in the cross section to reevaluate the evidence on the impact of the Federal Reserve swap arrangements as well as Federal Reserve and foreign central bank dollar auctions. This in keeping with the results in Rose and Spiegel (2009b) discussed above that find differences in performances during the financial crisis to be systematically related to the relative share of US assets and liabilities in national portfolios.

We will follow Aizenman and Pasricha (2010) in examining the responses to central bank actions for a broad set of countries. As in Baba and Packer (2009b), we will take as our event dates both the announcements of changes in international swap arrangements, as well as actual auctions conducted by foreign central banks using TAF auction proceeds.

However, our analysis differs from Aizenman and Pasricha (2010) in an important dimension. Their paper concentrates specifically on swap arrangements between a select set of emerging market economies (Brazil, Mexico, Korea, and Singapore) and the Federal Reserve. As they freely admit, this group that they dub the "selected four" was hardly chosen at random. All have disproportional liabilities to the United States, and there are other obvious considerations as well. For example, Korean officials were reportedly reluctant to obtain funds from the International Monetary Fund during the crisis due to its experience with that institution during the 1997 Asian Financial Crisis. Whatever the reason, the fact that only four emerging market countries were privy to such special treatment from the Federal Reserve demonstrates that they were not chosen at random. Moreover, while Aizenman and Pasricha (2010) try to condition for the selection stage in their work, they are limited to data that is available for a large cross section in their first stage specification.

We concentrate not on the smaller swap arrangements with individual emerging market nations, but on the major actions with industrial country central banks that were likely to have an impact on global dollar liquidity. Our model shows that improved global dollar liquidity will ease the liquidity constraint of an agent from a specific nation based on the exposure of that nation to the United States. Our model literally looks at liquidity shortages in trade, as illiquidity arises from inability to conduct desirable trade in a decentralized market, but in our empirical work we will also consider financial exposure to the United States, such as the exposure measures found to improve economic performances in Rose and Spiegel (2009b).

Since LIBOR rates are limited to a small set of developed nations, we follow Aizenman and Pasricha (2010) in using differences in CDS spreads as our indicator of liquidity risk.[15] Of course, changes in country creditworthiness will also affect CDS spreads, so we need to condition on country creditworthiness. This is problematic for the broad cross section that we use in our study, as many of the countries in our sample do not have widely-traded instruments that one might typically consider as potential indicators of changes in a country's creditworthiness.

In response, we use weekly search data obtained from Google trends. Google search data has now been used in a number of studies, such as Choi and Varian (2009)], who use search data results to predict levels of economic activity for automobile sales and unemployment figures. Use of such real-time data is most often used to describe current economic conditions, rather than forecast future ones, in a growing application commonly referred to as "nowcasting" [e.g. Varian (2010)].

This is the sense in which we use the Google search data in our study. To measure changes in the perceived sovereign risk of a country, we use the relative incidence of searches with a given country's name and words related to default. The list of words we use are risk, default, recession,

[15] Aizenman and Pasricha (2010) provide a theoretical model that links liquidity with CDS spreads.

deficit, debt, crisis, and bankruptcy, combined with an individual country name. We obtain a count of the number of searches with that country's name and at least one of our default-related search words. To protect proprietary data, Google only releases a time series of the relative number of searches for each country. This serves our purposes, however, as we are trying to explain the change in spreads, so we use the percentage change in search volume for a given country as a proxy for changes in concerns about default risk for that country.

While other estimates of changes in perceived country risk are not available at sufficiently high frequency for our broad cross-section, we can compare the results of the Google searches to lower frequency changes in perceived default risk to test whether our proxy is picking up such concerns. We use changes in Fitch ratings of long-term and short-term sovereign debt, and investigate whether changes in bond ratings are negatively correlated with search volume, i.e. if ratings downgrades are associated with increased default-related searches.

Preliminary results are shown in Table 2. It can be seen that there is a strong negative relationship between increases in Google search volumes and ratings downgrades, both contemporaneously, and with a one week lag. The latter is relevant since it is widely believed that actual ratings changes tend to lag changes in investor expectations about asset quality. This is supported by our data, although efforts to go farther out yielded insignificant correlations. Still, we find these results reassuring that the Google search volume data tracks changes in expectations about sovereign risk in the manner we desire.

We therefore take the following specification to a broad panel of emerging market and smaller developed economies:

$$\Delta CDS_{it} = \alpha_t + \theta_i + \beta_1 USexp_{it} * CBAnnounce_t + \beta_2 USexp_{it} * CBTAFauction_t + \beta_3 \Delta EIU_{it} + \epsilon_{it}. \tag{35}$$

where ΔCDS_{it} represents the change in CDS spreads from period $t-1$ to t, $USexp_{it}$ represents exposure to the United States by country i at time t, which we proxy through a number of alternative specifications of trade and financial exposure to the US along lines similar to the exposure measures in Rose and Spiegel (2009b), $CBAnnounce_t$ is an event dummy taking value one on dates coinciding with an announcement from the Federal Reserve concerning the establishment or expansion of its international swap operations and zero otherwise, $CBTAFauction_t$ is an event dummy taking value one on dates coinciding with an auction by a non-US central bank of dollar assets acquired through the TAF and zero otherwise, ΔEIU_{it} represents the change in underlying creditworthiness of nation i at time t, α_t and θ_i represent time and country fixed effects, and ϵ_{it} is a disturbance term, assumed to be well behaved.

Our specification then has the following intuition: We view each announcement concerning the international swap program, as well as each major industrial country dollar auction based on TAF funds as an event that can potentially impact global dollar liquidity. Given that this is the case, the model we derive below suggests that the sensitivity to that liquidity change will be dependent on national exposure to the United States. In this manner, we hope to avoid the endogeneity and timing issues that may have yielded the mixed results that have been found in the literature to date.

4.4 Results

While it is premature to report parametric results, we can report some correlation results concerning announcements of the TAF programs. We examine the univariate relationship between CDS spread changes and the announcements of the launch of the Federal Reserve swap programs and the removal of the ceiling on the swap arrangements respectively in Tables 3 and 4, and the overall impact of the ECB TAF auctions in our sample from 12/7 through 8/10 in Table 5. We report results for both 3 and 14 day event windows.

Our results are mixed, but the 14 day window results appear to be consistent with our theory, we get a negative coefficient on exposure throughout, which is statistically significant for the first announcement date and the TAF auctions. This suggests that more exposed countries had greater responses to the liquidity injection exercises.

Not all of our results are significant, and we have yet to include any conditioning variables, so these results should only be interpreted as suggesting that in a univariate sense, the data seem to match the predictions of the theory. More careful analysis is forthcoming.

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5 Appendix

5.1 Proof of Proposition 1

First, we demonstrate that the equilibrium prices are as stated. Consider a type 1 meeting with an agent from country k in which the agent from country z wants to buy $z, k = i, j$. By definition, the buyer can only use country k currency for the purchase in a type 1 meeting. Since the amount of the purchase in a type 1 meeting is equal to $\eta(q_{z,k,1})$, the value of currency holdings $M_{z,k}$ is equal to $\phi_k = \eta(q_{z,k,1})/M_{z,k}$.

Next, consider a type 2 meeting with the same pair of agents. In this meeting, the agent from country k will accept country k assets as well as currency. Since the buyer is illiquid, he uses all of his assets and currency in the transaction. It follows that $\eta(q_{k,z,1})$ of the transaction is financed by currency and $[\eta(q_{z,k,2}) - \eta(q_{z,k,1})]$ is left to be financed from the dividends earned on holdings of asset A_z, $\delta_k A_{z,k}$, as well as the sale of those holdings, valued at $\psi_z A_{z,k}$. It follows that $\delta_k A_{z,k} + \psi_z A_{z,k} = [\eta(q_{z,k,2}) - \eta(q_{z,k,1})]$, which can be solved for ψ_k as stated in Proposition 1.

Next, it can be seen by inspection in equations 27 and 28 that since λ_k is the same for agents from both countries, that $m_{i,k} = m_{j,k}$, i.e. agents from both countries hold the same amount of currency of country k ($k = i, j$). Moreover, by **??** and **??**, $m_{i,k} = m_{j,k} = M_k/2$. Similarly, given that $m_{i,k} = m_{j,k}$, it can be seen by inspection that equations 25 and 26 together with equations **??** and **??** imply that $a_{i,k} = a_{j,k} = A_{z,k}/2$.

Existence and uniqueness proofs remain to be done.

5.2 Proof of Proposition 2

We have four equations and four unknowns for the price and allocations of country i assets. The four equations are

$$\Lambda_1 \equiv \lambda_{i,i,1}\ell\left(q_{i,i,1}\right) I\left\{\omega_{i,i,1} < \eta\left(q*\right)\right\} + \lambda_{i,i,2}\ell\left(q_{i,i,2}\right) I\left\{\omega_{i,i,2} < \eta\left(q*\right)\right\} - \frac{1-\beta\gamma_i}{\beta\gamma_i} = 0$$

$$\Lambda_2 \equiv \lambda_{j,i,1}\ell\left(q_{j,i,1}\right) I\left\{\omega_{j,i,1} < \eta\left(q*\right)\right\} + \lambda_{j,i,2}\ell\left(q_{j,i,2}\right) I\left\{\omega_{j,i,2} < \eta\left(q*\right)\right\} - \frac{1-\beta\gamma_j}{\beta\gamma_j} = 0$$

$$\Lambda_3 \equiv \lambda_{i,i,2}\ell\left(q_{i,i,2}\right) I\left\{\omega_{i,i,2} < \eta\left(q*\right)\right\} - \frac{\psi_i - \beta\left(\psi_i + \delta_i\right)}{\beta\left(\psi_i + \delta_i\right)} = 0$$

$$\Lambda_4 \equiv \lambda_{j,i,2}\ell\left(q_{j,i,2}\right) I\left\{\omega_{j,i,2} < \eta\left(q*\right)\right\} - \frac{\psi_i - \beta\left(\psi_i + \delta_i\right)}{\beta\left(\psi_i + \delta_i\right)} = 0$$

To solve for the comparative static equations, recall that $\omega_{z,k,1} = \varphi_k m_{z,k}$ and $\omega_{z,k,2} = \varphi_k m_{z,k} + \left(\psi_k + \delta_k\right) a_{z,k}$, and

$$\frac{dq}{d\omega} = \frac{1}{\eta'\left(q\right)} = \frac{\left[\theta\upsilon' + \left(1-\theta\right)c'\right]^2}{\theta\left(1-\theta\right)\left(\upsilon - c\right)\left(\upsilon' c" - \upsilon" c'\right) + \theta\left(\upsilon'\right)^2 c' + \left(1-\theta\right)\upsilon'\left(c'\right)^2} \geq 0$$

Define the following

$$\sigma_{i,1} \equiv \lambda_{i,i,1}\ell'\left(q_{i,i,1}\right)\frac{dq_{i,i,1}}{d\omega} I\left\{\omega_{i,i,1} < \eta\left(q*\right)\right\} < 0$$

$$\sigma_{i,2} \equiv \lambda_{i,i,2}\ell'\left(q_{i,i,2}\right)\frac{dq_{i,i,2}}{d\omega} I\left\{\omega_{i,i,2} < \eta\left(q*\right)\right\} < 0$$

$$\sigma_{j,1} \equiv \lambda_{j,i,1}\ell'\left(q_{j,i,1}\right)\frac{dq_{j,i,1}}{d\omega} I\left\{\omega_{j,i,1} < \eta\left(q*\right)\right\} < 0$$

$$\sigma_{j,2} \equiv \lambda_{j,i,2}\ell'\left(q_{j,i,2}\right)\frac{dq_{j,i,2}}{d\omega} I\left\{\omega_{j,i,2} < \eta\left(q*\right)\right\} < 0$$

Then the comparative static equations of the system satisfy

$$\begin{bmatrix} (\sigma_{i1}+\sigma_{i2})\,m_{ii} & (\sigma_{i1}+\sigma_{i2})\,\varphi_i & \sigma_{i2}a_{ii} & \sigma_{i2}\,(\psi_i+\delta_i) \\ (\sigma_{j1}+\sigma_{j2})\,(m_i-m_{ii}) & -(\sigma_{j1}+\sigma_{j2})\,\varphi_i & \sigma_{j2}\,(a_i-a_{ii}) & -\sigma_{j2}\,(\psi_i+\delta_i) \\ \sigma_{i2}m_{ii} & \sigma_{i2}\varphi_i & \sigma_{i2}a_{ii}-\delta_i\beta^{-1}\,(\psi_i+\delta_i)^{-2} & \sigma_{i2}\,(\psi_i+\delta_i) \\ \sigma_{j2}\,(m_i-m_{ii}) & -\sigma_{j2}\varphi_i & \sigma_{j2}\,(a_i-a_{ii})-\delta_i\beta^{-1}\,(\psi_i+\delta_i)^{-2} & -\sigma_{j2}\,(\psi_i+\delta_i) \end{bmatrix}$$

$$\Phi=(\psi_i+\delta_i)\,\varphi_i\sigma_{i2}\sigma_{j2}\,[\sigma_{i1}\sigma_{j2}+\sigma_{i1}\,(\sigma_{j1}+\sigma_{j2})]\,m_ia_i-\tfrac{\varphi_i\delta_i}{\beta(\psi_i+\delta_i)}\,(\sigma_{i1}\sigma_{i2}\,(\sigma_{j1}+\sigma_{j2})+(\sigma_{i1}+\sigma_{i2})\,\sigma_{j1}\sigma_{j2})\,m_i\geq 0$$

So the determinant is positive

Differentiating Λ_1, Λ_2,Λ_3,Λ_4, with respect to δ_i yields

$$\frac{\partial\Lambda_1}{\partial\delta_i}=\sigma_{i2}a_{ii}\leq 0$$

$$\frac{\partial\Lambda_2}{\partial\delta_i}=\sigma_{j2}\,(a_i-a_{ii})\leq 0$$

$$\frac{\partial\Lambda_3}{\partial\delta_i}=\sigma_{i2}a_{ii}+\psi_i\beta^{-1}\,(\psi_i+\delta_i)^{-2}$$

$$\frac{\partial\Lambda_4}{\partial\delta_i}=\sigma_{j2}\,(a_i-a_{ii})+\psi_i\beta^{-1}\,(\psi_i+\delta_i)^{-2}$$

To calculate $\partial\varphi_i/\delta_i$, the numerator matrix satisfies

$$\begin{bmatrix} -\sigma_{i2}a_{ii} & (\sigma_{i1}+\sigma_{i2})\,\varphi_i & \sigma_{i2}a_{ii} & \sigma_{i2}\,(\psi_i+\delta_i) \\ -\sigma_{j2}\,(a_i-a_{ii}) & -(\sigma_{j1}+\sigma_{j2})\,\varphi_i & \sigma_{j2}\,(a_i-a_{ii}) & -\sigma_{j2}\,(\psi_i+\delta_i) \\ -\sigma_{i2}a_{ii}-\psi_i\beta^{-1}\,(\psi_i+\delta_i)^{-2} & \sigma_{i2}\varphi_i & \sigma_{i2}a_{ii}-\delta_i\beta^{-1}\,(\psi_i+\delta_i)^{-2} & \sigma_{i2}\,(\psi_i+\delta_i) \\ -\sigma_{j2}\,(a_i-a_{ii})-\psi_i\beta^{-1}\,(\psi_i+\delta_i)^{-2} & -\sigma_{j2}\varphi_i & \sigma_{j2}\,(a_i-a_{ii})-\delta_i\beta^{-1}\,(\psi_i+\delta_i)^{-2} & -\sigma_{j2}\,(\psi_i+\delta_i) \end{bmatrix}$$

The determinant of this matrix satisfies

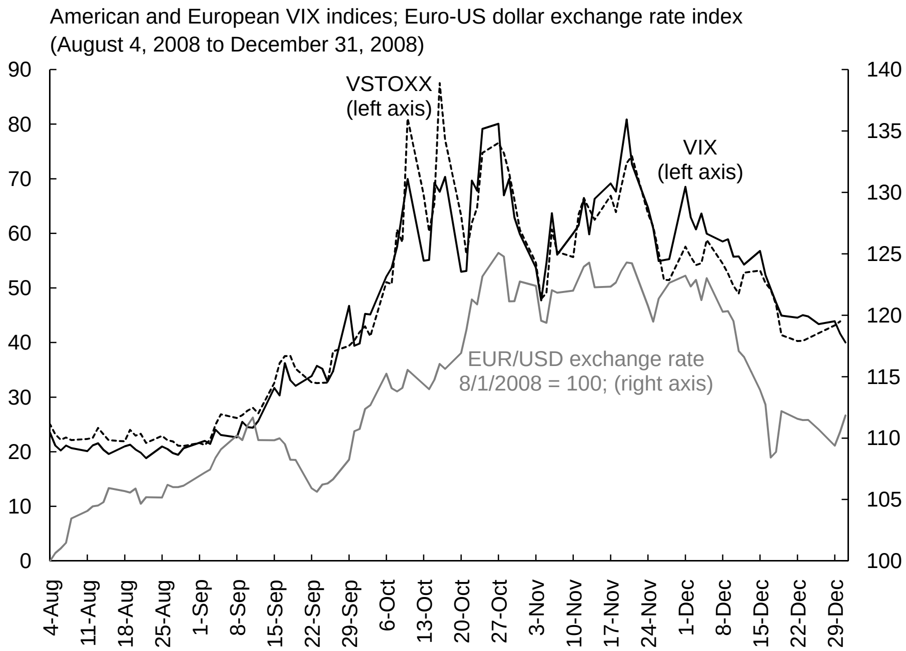
$$\Phi=(\sigma_{i1}+\sigma_{j1})\,\sigma_{i2}\sigma_{j2}\varphi_i\beta^{-1}a_i\leq 0$$

So by Cramer's rule, the comparative statics satisfy

$$\frac{\partial \varphi_i}{\partial \delta_i} = \frac{(\sigma_{i1} + \sigma_{j1})\,\sigma_{i2}\sigma_{j2}\,(\psi_i + \delta_i)\,a_i}{m_i\left[\beta\,(\psi_i + \delta_i)^2\,\sigma_{i1}\sigma_{i2}\sigma_{j2}\,(\sigma_{j1} + 2\sigma_{j2})\,a_i - \delta_i\,(\sigma_{i1}\sigma_{i2}\,(\sigma_{j1} + \sigma_{j2}) + (\sigma_{i1} + \sigma_{i2})\,\sigma_{j1}\sigma_{j2})\right]} \leq 0$$

as stated in Proposition 2.

Figure 1: Stock Market Volatility and Bilateral Exchange Rate



Sources: Bloomberg and DistFAME
VIX and VSTOXX indicies of equity market volatility in United States and European exchanges respectively.
Dollar-euro exchange rate indexed to 100 on August 1, 2008.

Figure 2: Ratings changes and Google search volumes: Iceland

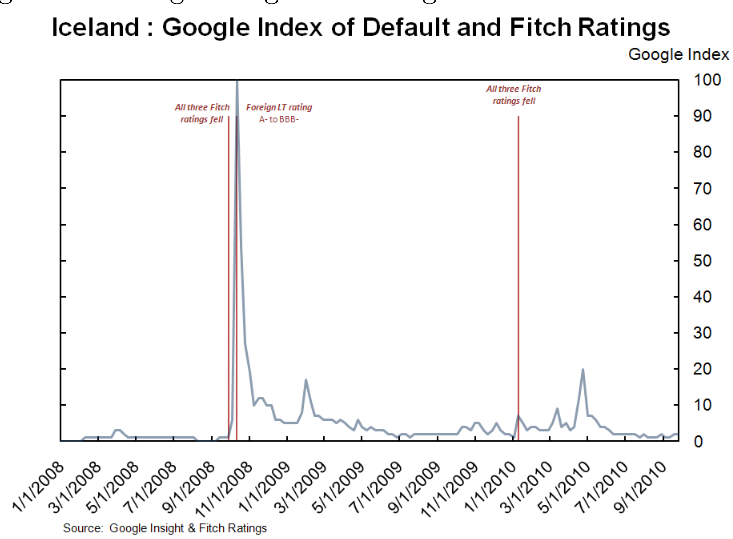


Table 1: Financial Linkages and Exposure to the United States

Linkage (2006)	Variable description	Coeff. estimate
CPIS Asset Share	Foreign holdings of US assets,	0.27*
	share of total external foreign assets	(0.10)
CPIS Debt Share	Foreign holdings of US debt,	0.19*
	share of total external foreign assets	(0.09)
CPIS Long Debt Share	Foreign holdings of US long-term debt,	-0.64
	share of total external foreign assets	(1.26)
BIS Consolidated Banking Share	Foreign banks' financial claims on US,	131
	scaled by total foreign exposure	(88)
US TIC Assets/GDP	Foreign holdings of US assets,	0.19
	scaled by GDP	(1.39)
US TIC Equity/GDP	Foreign holdings of US equity,	1.01
	scaled by GDP	(3.96)
US TIC Long Debt/GDP	Foreign holdings of US long-term debt,	0.32
	scaled by GDP	(2.30)
US TIC Debt/GDP	Foreign holdings of US debt,	0.22
	scaled by GDP	(2.02)
US TIC Treasuries/GDP	Foreign holdings of US treasuries,	3.77
	scaled by GDP	(12.14)
US TIC Long Treasuries/GDP	Foreign holdings of US long-term treasuries,	3.55
	scaled by GDP	(13.75)
%PPG Debt in $	Percent of public and publicly-guaranteed	0.21*
	debt denominated in USD	(0.10)

Source: Rose and Spiegel (2009b)
Notes: Coefficient estimates from default specification. Linkages are based on exposure values in 2006. Crisis manifestations are based on national performances in 2008. See Rose and Spiegel (2009b) for full specification.
* indicates significance at 5% confidence level.

Table 2: Google searches and sovereieign ratings

Regression: Percent change in Google index on rating changes			
Regressor	Observations	Coefficient	T-value
Local LT	8636	-60.786	-16.32
Foreign LT	8651	-60.216	-9.60
Foreign ST	8929	-74.938	-6.22
Local LT (week ahead)	8594	-16.734	-4.46
Foreign LT (week ahead)	8608	-16.771	-2.66
Foreign ST (week ahead)	8886	-19.744	-1.63

Table 3: Impact of announcements on CDS spreads

Swap Lines Introduced 12/12/07		
time window	Asset Share	Trade Share
3 day	.04500668	.030203
3 day	(.0573778)	(.0765349)
14 day	-.55951**	-.7090916*
14 day	(.1630593)	(.303195)

Table 4: Impact of unlimited swap announcement on CDS spreads

Unlimited Swaps Announced 10/13/2008		
time window	Asset Share	Trade Share
3 Day	.0450068	.030203**
3 Day	(.0573778)	(.0765349)
14 Day	-.55951	-.7090916
14 Day	(.1630593)	(.909195)

Table 5: Impact of ECB TAF auctions on CDS spreads (12/07-8/10)

All ECB Auction Dates		
time window	Asset Share	Trade Share
3 Day	-.0042184	-.0078648
3 Day	(.0068884)	(.0125716)
14 Day	-.0353312*	-.0915262**
14 Day	(.0152053)	(.0259898)