Agency MBS as Safe Assets *

Zhiguo He† Zhaogang Song‡

December 31, 2020

Preliminary and comments welcome

Abstract

We provide evidence on agency mortgaged-backed securities (MBS) as safe assets by examining the effects of the demand for them relative to other safe assets. Over 1993 – 2018, the average MBS convenience premium is 47 basis points and about half of the Treasury convenience premium, both measured as yield spreads against AAA corporate bonds. The placing of agencies into conservatorship in 2008 and introduction of liquidity coverage ratio since 2014, as two quasi-natural experiments of shocks to MBS demand, affect convenience premium significantly in the respective time windows. The mortgage rate, which can drive the demand for MBS through the effect on prepayment-related valuation complexity, negatively affects MBS convenience premium and issuance in the long sample. The MBS convenience premium is also present in repo market.

Keywords: Convenience, Liquidity, MBS, Monetary Economics, Safe Asset

JEL classification: G12, G18, G21, E58

*For helpful comments, we thank Ye Li, Francis Longstaff, Nagpurnanand Prabhala, and Steve Schaefer, as well as participants at the Johns Hopkins Carey seminar and the 7th International Conference on Sovereign Bond Markets.

†Booth School of Business, University of Chicago, and NBER; 5807 South Woodlawn Avenue, Chicago, IL 60637. E-mail: zhiguo.he@chicagobooth.edu.

‡The Johns Hopkins Carey Business School, 100 International Drive, Baltimore, MD 21202. E-mail: zsong8@jhu.edu.

1 Introduction

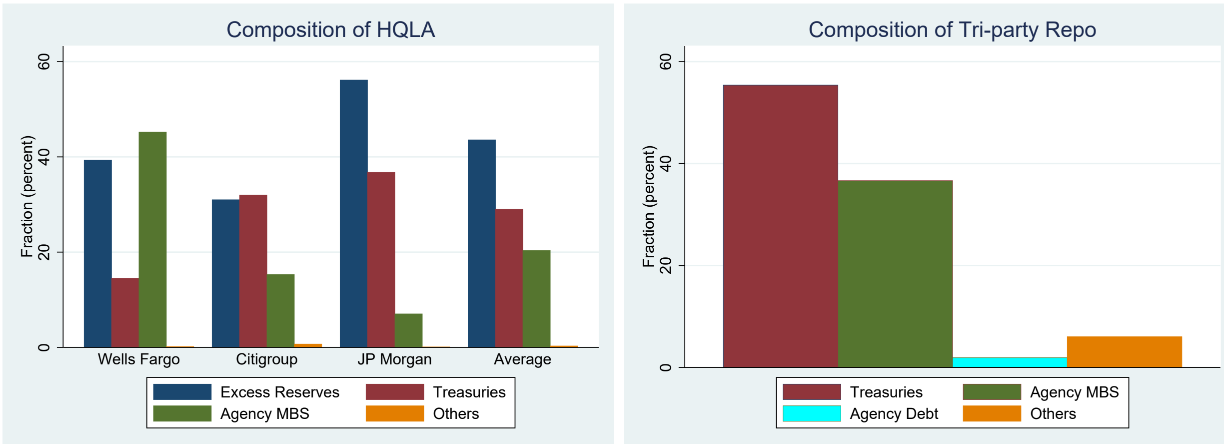
Safe assets, serving as important liquidity reserves and stable stores of value, "play a critical role in the economy and have implications for transactions and savings efficiency, financial crises, general aggregate macroeconomic activity, and monetary policy" (Gorton (2017)). What assets are safe assets? The literature has mainly focused on reserves at central banks, Treasury securities, and federal agency debt as public safe assets (such as Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), and Greenwood, Hanson, and Stein (2015)), and bank deposit, asset-backed commercial paper, repurchase agreement, and private-label asset-backed securities as private safe assets (such as Xie (2012), Sunderam (2014), Carlson and Wheelock (2018), and Kacperczyk, Pérignon, and Vuillemey (2019)). In this paper, we provide evidence on agency mortgage-backed securities (MBS) guaranteed by Fannie Mae, Freddie Mac, and Ginnie Mae as safe assets.

There is ample anecdotal evidence for the nature and role of agency MBS as safe assets. First, with principal balance essentially backed by U.S. government, the safety of agency MBS is close to that of Treasury securities. Second, in the liquidity coverage ratio (LCR) requirement of Basel III, agency MBS are an important component of "high-quality liquid assets (HQLA) that can be converted easily and immediately in private markets into cash" (Bank for International Settlements (2013)). From Figure 1, the fraction of agency MBS in HQLA holdings by several major banks is about 20%, as of December 2018, lower than Treasury securities (30%), but higher than all other long-term securities (up to 1%).[1] Third, agency MBSs are widely accepted as collateral for repo financing, which can cushion temporary liquidity shocks conveniently. Figure 1 shows that MBSs account for 37% of the total \$1.95 trillion of tri-party repo amount, again lower than Treasury securities (55%) but higher than all others combined. Finally, MBSs are a critical component of monetary policy operations, experiencing purchases by the Federal Reserve (Fed) during the 2008 crisis and recent COVID-19 crisis again, which strengthen their safety status.

Surprisingly, little has been done in the literature on the economic role of agency MBS as safe assets thus far. In this paper, we provide the first analysis to measure the MBS

[1] These are JP Morgan, Wells Fargo, and Citigroup, which are among the very few that separate the amount of excess reserves and Treasuries in their LCR disclosure reports. The estimates of Treasuries have a potential upward bias as they may include Ginnie Mae securities and foreign sovereign bonds, whereas the estimates of agency MBS have both a potential upward bias from including agency debt and a potential downward bias from missing Ginnie Mae MBS. Ihrig, Kim, Vojtech, and Weinbach (2019) conduct a detailed calculation of HQLA and find that agency MBS account for a even larger fraction, about 40% of the total HQLA holdings, for 15 bank-holding companies (including JP Morgan, Wells Fargo, and Citigroup) with \$250 billion or more in total assets or \$10 billion or more in on-balance sheet foreign exposures.

Figure 1: HQLA and Repo



Note: The left panel reports the fraction of excess reserves, Treasuries, agency MBS, and other securities such as corporate and municipal bonds of HQLA over 2018:Q4 for Citigroup, Wells Fargo, and JP Morgan, respectively, as well as the average across the three banks. The respective average weighted (by haircut) amount of HQLA is $ 404, 367, and 529 billion. The right panel reports the fraction of Treasuries, agency MBS, agency debt, and other investment grade assets (including investment grade ABS, private-label CMO, and corporate bonds, as well as municipal bonds and money market instruments) of tri-party repo outstanding balance as of December 2018. The total amount of outstanding tri-party repo is $1.95 trillion.

convenience premium and examine its distinctive economic drivers. Our analysis mainly focuses on the effects of the demand for agency MBS relative to other safe assets.

We first provide a simple model to demonstrate the economic channel and guide the empirical analysis. Similar to Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), and Sunderam (2014), we use standard money-in-the-utility function where investors derive utility from safe asset holdings directly. The holdings consist of agency MBS and other safe assets (Treasury securities particularly) that are substitutable. The utility benefit investors derive leads to a convenience premium on prices of safe assets. The MBS supply is chosen endogenously by banks who maximize profits in securitizing mortgage loans, while the supply of Treasury securities is exogenously determined by the government.[2] The equilibrium MBS convenience premium and supply endogenously depend on the exogenous demand for MBS *relative* to other safe assets (denoted as λ_t), which is our main focus. They also depend on the government's supply of Treasury securities and the demand for *all* safe assets (denoted

[2]Same implications would be obtained if banks simply securitize any mortgage loan taken by borrowers rather than optimize on the amount of mortgage loan to securitize. That is, whether banks or mortgage borrowers are assumed to be marginal suppliers of MBS in the model is not essential in capturing the relationship between the MBS supply and convenience premium. Both should play a role in practice.

as γ_t) that, for example, captures a broad flight-to-safety in recessions.

In taking model implications to empirical testing, we specify the MBS demand λ_t as consisting of two components. The first component captures shocks to MBS demand regardless of prepayment risk, e.g., certain policy initiations involving MBS or capital flows of foreign investors into the US market (Bernanke (2005)). The second component captures variations in investors' demand related to low prepayment risk. For example, the complexity of prepayment modeling in valuing prepayment risk (Eisfeldt, Lustig, and Zhang (2019); Li and Song (2020)) can lead to value uncertainty or information sensitivity and lowers investors' demand for MBS (Gorton and Pennacchi (1990); Caballero and Simsek (2013)). We provide evidence for the effects of both components on MBS convenience premium.

To measure MBS convenience premium, we use the spread of MBS yields relative to two benchmark yields, those of AAA rated corporate bonds that have lower safety and those of Treasury securities that have higher safety, on average. The MBS yields are adjusted for prepayment options (Gabaix, Krishnamurthy, and Vigneron (2007), Boyarchenko, Fuster, and Lucca (2019), and Song and Zhu (2019)), available from October 1993 to December 2018 at the monthly frequency. We show that the mean convenience premium of newly issued 30-year Fannie Mae MBS is 46 basis points (bps), about half of that of Treasury securities, both measured against AAA corporate bonds. In addition, the monthly new issuance of 30-year Fannie Mae MBS is used to measure MBS supply, averaging about $27 billion.

Using the two MBS yield spreads as measures of convenience premium, we first study the effects of non-prepayment-related shocks to MBS demand. In particular, we use two policy events as quasi-natural experiments. The first is the placing of Fannie Mae (and Freddie Mac) into conservatorship on September 6, 2008 that is officially backed by the U.S. Treasury department. Before the conservatorship, they were private entities with only implicit U.S. government support. The conservatorship would naturally induce an increase in the demand for MBSs of Fannie Mae relative to those of Ginnie Mae, which has long been a wholly-owned government corporation. The second policy event is the progressive implementation of LCR rule since 2014, in which Fannie Mae and Ginnie Mae MBSs receive a haircut of 15 and zero percent, respectively, in computing the amount of HQLA holdings. This would induce an decrease in banks' demand for Fannie Mae MBS relative to Ginnie Mae MBS. We exploit both of the policy shocks using a different-in-difference analysis.

We find that MBS convenience premium of Fannie Mae mostly stayed lower than that of Ginnie Mae before the conservatorship but went up above afterwards. The situation is reversed, with the MBS convenience premium of Fannie Mae moving down below that of Ginnie Mae around January 2014 when LCR began to phase in. These are consistent with an increase (decrease) in demand for the Fannie Mae MBS relative to Ginnie Mae MBS associated with the conservatorship (LCR) shock. Difference-in-difference regressions using sample with one-year window quantify the effects of conservatorship and LCR to be about 49 and 15 bps, respectively. Adjusting the MBS yields by CDS spreads on Fannie Mae, which removes the credit component, reduces the estimated conservatorship effect to about 35 bps, but does not affect the estimated LCR effect.

Turning to prepayment-related variations in MBS demand, we study the dependence of MBS convenience premium and issuance on mortgage rate. Specifically, mortgage rate serves as the "multiplier" of prepayment modelling complexity and negatively affects MBS demand because MBS of higher mortgage rate carries higher prepayment incentive. A negative effect is hence expected. Empirically, this prepayment-related effect allows us to capture variations in convenience premium in the long sample from 1993 to 2018 as opposed to short time windows used above.

Monthly time series regressions show that a negative effect is indeed the case. Economically, a one-standard-deviation increase in mortgage rate decreases the MBS convenience premium by about 10 bps. This magnitude is remarkably same using either of the two yield spreads, greatly mitigating concerns on confounding effects specific to either corporate bonds or Treasury securities. Further, a one-standard-deviation increase in mortgage rate decreases the monthly MBS issuance by about 50%. In addition, we also find that a one-standard-deviation increase in Treasury supply, proxied by U.S. debt to GDP ratio, decreases the monthly MBS issuance by about 55% (the effect on convenience premium is only about 4 bps). That is, the government's Treasury supply strongly crowds out MBS issuance, consistent with their substitutability in satisfying safe asset demand.

We document evidence inconsistent with three alternative interpretations. First of all, mortgage rate may proxy demand for all safe assets (γ_t) rather than the demand for MBS relative to other safe assets (λ_t). However, the AAA-MBS spread and Treasury-MBS spread should depend on γ_t with opposite signs. Intuitively, this is because increasing γ_t would decrease the AAA (Treasury) yield less (more) than the MBS yield due to its lower (higher) safety. The negative dependence of both yield spreads on mortgage rate is hence against this alternative interpretation. Second, using mortgage rate to proxy for demand shift λ_t is subject to an endogeneity concern: an unobservable negative MBS demand shock, which decreases MBS convenience premium and issuance, can lead to a rise in mortgage rate with lower convenience benefits passed on to mortgage borrowers. Federal funds rate (FFR) is unlikely to be subject to this concern because it is arguably controlled by the Federal Reserve. Importantly, if the Fed responds to the unobservable negative demand shock, FFR would be cut downward to depress increasing mortgage rate, which is opposite to their significant positive association in the data. Regressions of AAA-MBS and Treasury-MBS spreads and MBS issuance on FFR deliver significantly negative coefficients indeed, similar to mortgage rate. Third, regressing MBS convenience premium on issuance gives a significantly positive coefficient, inconsistent with supply-driven channels that would imply a negative one.

We finally study the association of MBS convenience premium and the value of MBS serving as collateral for repo financing, through which investors can obtain funding to cushion temporary liquidity shocks conveniently. To measure the collateral value of agency MBS, we use the spread in overnight repo rates of Treasury securities and agency MBS. This repo spread has a mean of -6 bps from January 2005 to December 2018, showing that Treasury securities carry a higher average collateral value than agency MBS in repo markets. Regressing the Treasury-MBS repo spread on yield spread delivers a significantly positive coefficient, and an adjusted R^2 of 32%. Further, the regression coefficient of the repo spread on mortgage rate is significantly negative. Economically, a one-standard-deviation increase in mortgage rate decreases the repo spread by about 5 bps, over 80% of the mean repo spread. Hence, MBS collateral value and convenience premium are significantly associated with either other, pointing to a market equilibrium with both determined jointly.

We conduct a number of additional analyses and robustness checks. For example, by comparing MBS of 15-year vs 30-year and of Ginnie Mae vs Fannie Mae, we show that MBS with stronger government backing and shorter maturity are in higher demand. Moreover, our main results are robust to including VIX and slope of the term structure as controls for credit risk and potential maturity mismatch between corporate bonds and agency MBS in measuring convenience premium (Krishnamurthy and Vissing-Jorgensen (2012)), to potential misspecification of prepayment models by using MBS yields from different dealers and controlling for prepayment rates in regressions, and to strong using monthly changes.

Related literature. To the best of our knowledge, this paper provides the first analysis on agency MBS as safe assets. It mainly contributes to the expanding literature on safe assets' supply and demand, including early studies by Bansal and Coleman (1996), Duffee (1996), and Longstaff (2004) and recent studies by Gorton, Lewellen, and Metrick (2012), Krishnamurthy and Vissing-Jorgensen (2015), Bansal, Coleman, and Lundblad (2011), Nagel (2016), Xie (2012), Sunderam (2014), Du, Im, and Schreger (2018), Fleckenstein and Longstaff (2018), Kacperczyk, Pérignon, and Vuillemey (2019), Jiang, Krishnamurthy, and Lustig (2019b), and He, Nagel, and Song (2020), among others (see Gorton (2017) and Caballero, Farhi, and Gourinchas (2017) for two broad surveys on safe assets). None of these have examined the distinctive economic drivers of agency MBS as safe assets.[3]

The concept of safe asset is elusive, often used with an operational definition (Caballero and Farhi (2017)). The theoretical literature has modelled several economic channels, such as Gorton and Pennacchi (1990), Gorton and Ordoñz (2014), and Dang, Gorton, and Holmström (2015) on information sensitivity, Caballero and Simsek (2013) on complexity, and He, Krishnamurthy, and Milbradt (2019) and Farhi and Maggiori (2017) on coordination.[4] The main empirical determinant of MBS convenience premium in our analysis is tied to the channel of information sensitivity or asset complexity.

This paper is also related to recent studies of agency MBS pricing, with Gabaix, Krishnamurthy, and Vigneron (2007), Duarte, Longstaff, and Yu (2007), Chernov, Dunn, and Longstaff (2018), Boyarchenko, Fuster, and Lucca (2019), Diep, Eisfeldt, and Richardson (2017), Carlin, Longstaff, and Matoba (2014), Hansen (2014), Chen, Liu, Sarkar, and Song (2020), and Fusari, Li, Liu, and Song (2020). We contribute to this literature by showing that agency MBS yields contain an important convenience premium component due to their safety and liquidity.[5] In addition, the analysis on relation between agency MBS repo rate and convenience premium complements Lenel, Piazzesi, and Schneider (2019) who study the collateral value of safe assets in general and Bartolini, Hilton, Sundaresan, and Tonetti (2011) and Song and Zhu (2019) who study financing markets of agency MBS in particular.

2 Model and Predictions

In this section, we present a simple model to flesh out important implications if investors regard agency MBS as a class of safe assets. The model setup is standard, with agents deriv-

[3]Relatedly, see Nothaft, Pearce, and Stevanovic (2002) and references therein for studies of the yield spread of Fannie Mae and Freddie Mac debt to non-GSE debt. This yield spread captures the lower (corporate) funding cost of GSEs, different from the agency MBS convenience premium that is related to potential lower funding cost of mortgage borrowers.

[4]Relatedly, there is a macroeconomic literature on the role of global imbalance, safe asset shortage, and monetary policy, including Bernanke (2005), Caballero (2006), Caballero, Farhi, and Gourinchas (2008), Maggiori (2017), and Jiang, Krishnamurthy, and Lustig (2019a).

[5]A related literature studies MBS market liquidity and trading, including Bessembinder, Maxwell, and Venkataraman (2013), Downing, Jaffee, and Wallace (2009), Gao, Schultz, and Song (2017, 2018), Schultz and Song (2019), and Li and Song (2019).

ing utility directly from holdings of safe assets, based on the money-in-the-utility framework in the monetary economics literature (see also Walsh (2017)). When deriving implications for empirical testing, we postulate a particular specification for the driving forces of the safe asset demand for agency MBS.

2.1 Model

Safe asset demand. A representative (household) saver, endowed with a stream of perishable consumption good $\{A_t\}$, seeks to maximize

$$E_0 \left\{ \sum_{t=1}^{\infty} \beta^t \left[u\left(C_t\right) \right] \right\},$$

where $C_t \equiv c_t + \gamma_t v\left(Q_t\right)$, c_t is the agent's consumption at date t, and $Q_t = B_t + \lambda_t M_t$ is the total amount of real liquidity holding with M_t and B_t the real balances of MBS and other safe assets, respectively. The "convenience" benefits the agent derives from Q_t are modelled as a reduced-form function $v(Q_t)$, which is assumed to be $log(Q_t)$ similar to Nagel (2016). In general, B_t can be the outstanding balance of any safe assets, e.g., Treasury securities and high-rating corporate bonds. We mainly consider Treasury securities, so assume B_t is exogenously controlled by the government. In contrast, the real outstanding balance M_t of MBS will be endogenously determined in equilibrium.

The parameter γ_t captures time-varying demand for *all* safe assets. For example, when the market experiences a general flight-to-safety from risky assets, a higher γ_t arises because of the stronger demand for safe assets like Treasuries and agency MBS due to their explicit and implicit government guarantee. Importantly, as the paper's main focus, the parameter λ_t captures time-varying demand for MBS relative to other safe assets, i.e., Treasury securities specifically. This can reflect time variation in the agent's perception of the usefulness of MBS, relative to the same quantity of Treasuries, for the purpose of liquidity holding. We assume $\lambda_t < 1$ to reflect the fact that Treasuries are of higher safety than agency MBS ($\lambda_t > 1$ if B_t is the real balance of corporate bonds).

The saving household maximizes her lifetime utility subject to the following flow budget constraint:

$$B_{t-1} P_t^B + M_{t-1} P_t^M + A_t = C_t + B_t P_t^B + M_t P_t^M, \tag{1}$$

where P_t^B and P_t^M are the respective (real) prices of Treasuries and MBS in units of consumptions, and A_t is the endowment in period t.[6] The agent's problem is to choose paths for c_t, B_t, and M_t for optimization.

The first order condition for c_t is

$$1+\beta E_t\left[\frac{u'\left(C_{t+1}\right)}{u'\left(C_t\right)}\left(-\frac{P_{t+1}^B}{P_t^B}\right)\right]=0, \tag{2}$$

while the first order condition for M_t is

$$\gamma_t v'\left(Q_t\right)\lambda_t+\beta E_t\left[\frac{u'\left(C_{t+1}\right)}{u'\left(C_t\right)}\left(-P_t^M\frac{P_{t+1}^B}{P_t^B}+P_{t+1}^M\right)\right]=0. \tag{3}$$

Intuitively, a unit increase of holdings in M_t leads to an increase of $\gamma_t v'\left(Q_t\right)\lambda_t$ in time-t utility and an increase of $\beta E_t\left[\frac{u'(C_{t+1})}{u'(C_t)}P_{t+1}^M\right]$ in time-$(t+1)$ utility, but a decrease of $\beta E_t\left[\frac{u'(C_{t+1})}{u'(C_t)}\left(P_t^M\frac{P_{t+1}^B}{P_t^B}\right)\right]$ in time-$(t+1)$ utility. Combining equations (2) and (3), we have

$$P_t^M=\lambda_t\gamma_t v'\left(Q_t\right)+\beta E_t\left[\frac{u'\left(C_{t+1}\right)}{u'\left(C_t\right)}P_{t+1}^M\right]. \tag{4}$$

Similarly, for Treasuries, we have

$$P_t^B=\gamma_t v'\left(Q_t\right)+\beta E_t\left[\frac{u'\left(C_{t+1}\right)}{u'\left(C_t\right)}P_{t+1}^B\right]. \tag{5}$$

To derive conditions on the convenience premiums, we consider, for simplicity, one-period Treasuries and MBS, so that $P_{t+1}^M=1$ and $P_{t+1}^B=1$. Define the MBS yield as $r_t^M\equiv-\ln\left(P_t^M\right)$. Then we have

$$\begin{aligned} r_t^M &\approx 1-P_t^M \\ &= 1-E_t\left[\frac{\beta u'\left(C_{t+1}\right)}{u'\left(C_t\right)}\right]-\lambda_t\gamma_t v'\left(Q_t\right) \\ &\approx r_t-\lambda_t\gamma_t v'\left(Q_t\right). \end{aligned}$$

where equation (4) is used in the second equality, and $r_t\approx 1-E_t\left[\frac{\beta u'(C_{t+1})}{u'(C_t)}\right]$ is the real rate applicable to assets and transactions that do not produce a safety service flow. We define

[6] This setup implicitly assumes that it is the agent's real liquidity holdings at the end of the period, after having purchased consumption goods, that yield utility. Alternative timing assumptions, e.g., liquidity holdings available *before* the purchase of consumption goods yield utility, do not change the main implications. See Carlstrom and Fuerst (2001) for such an alternative timing assumption and Walsh (2017) for general discussions.

the convenience premium of MBS as

$$y_t^M \equiv r_t - r_t^M = \lambda_t \gamma_t v'(Q_t). \tag{6}$$

Similarly, the convenience premium for Treasuries is defined as

$$y_t^B \equiv r_t - r_t^B = \gamma_t v'(Q_t). \tag{7}$$

Equations (6) and (7) describe the saving household's demand for MBS and Treasuries as safe assets.

Safe asset supply. The supply of Treasuries is exogenously determined by the government, similar to Krishnamurthy and Vissing-Jorgensen (2012), while the supply of MBS is chosen endogenously by banks who maximize profits. Specifically, there is a continuum of banks of mass one, who securitize mortgage loans from rate-inelastic mortgage borrowers as MBS, which they then sell to saving households. Assuming that mortgage borrowers are rate-inelastic captures the rigid housing demand in practice.

Banks essentially serve as intermediaries for loans saving households make to mortgage borrowers. For an M_t amount of MBS, mortgage borrowers are willing to pay a rate up to r_t (maximum willingness-to-pay), while by equation (6), saving households require a rate of r_t^M. Therefore, the total gain is $M_t(r_t - r_t^M) = M_t y_t^M$. We assume that banks extract the whole gain using their market power (Scharfstein and Sunderam (2017)). We further assume that banks have a private cost $\kappa(M_t)$ with $\kappa'(\cdot) > 0$ and $\kappa''(\cdot) > 0$ similar to Sunderam (2014). Banks' profit maximization problem is

$$\max_{M_t} \left\{ y_t^M M_t - \kappa(M_t) \right\}. \tag{8}$$

The first order condition is

$$\kappa'(M_t) = y_t^M. \tag{9}$$

Because $\kappa''(\cdot) > 0$, M_t is a monotonically increasing function of y_t^M , all else equal. Under this setup on banks, the primary mortgage rate paid by borrowers is equal to r_t.

Equilibrium. To summarize the equilibrium, let $\phi(\cdot) = [\kappa'(\cdot)]^{-1}$, then we have

$$M_t = \phi\left(y_t^M\right) \tag{10}$$

based on equation (9). Plugging this into (6) and (7), we have

$$y_t^M = \lambda_t \gamma v'\left(B_t + \lambda_t \phi\left(y_t^M\right)\right), \quad (11)$$

$$y_t^B = \gamma v'\left(B_t + \lambda_t \phi\left(y_t^M\right)\right). \quad (12)$$

Note that the supply of Treasuries B_t is exogenously controlled by the government but the supply of MBS M_t is endogenously determined by banks, so the equilibrium involves endogenous y_t^M, y_t^B, and M_t as functions of exogenously parameters and functions λ_t, γ_t, $v(\cdot)$, B_t, and $\kappa(\cdot)$.[7] The following proposition formally defines the equilibrium for safe assets.

Proposition 1. ***[Market equilibrium of safe assets]*** *The market equilibrium for safe assets is given by Equations (10), (11), and (12), which define the equilibrium convenience premiums y_t^M and y_t^B, as well as the equilibrium quantity M_t.*

Discussion of model setup. Before deriving implications, several aspects of the model setup are worth discussing. First, the demand for safe assets is modelled based on the money-in-the-utility (MIU) framework by assuming that liquidity holdings yield utility directly (Sidrauski (1967)). Alternative frameworks, including Baumol (1952), Tobin (1956), Clower (1967), Lucas (1980), Kiyotaki and Wright (1989), and Brock (1974) among others, emphasize the transaction role of money that are arguably more micro-founded. Yet, some of these frameworks are actually equivalent to a MIU function (Brock (1974) and Feenstra (1986)). More importantly, our focus is on empirically documenting the role of MBS as safe assets, so a simple and stylized model that can parsimoniously flesh out implications of the safety attribute of MBS for equilibrium price and quantity is a good compromise. This is similar to most of the asset pricing studies of safe assets including Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), and Sunderam (2014).

Second, in the model, banks make mortgage loans to mortgage borrowers and securitize them into MBS that are subsequently sold in the secondary market to savers as ultimate holders. In practice, there is a chain of intermediation between mortgage borrowers and savers. In particular, it is usually commercial banks, broadly defined, who lend to mortgage borrowers directly. They also execute the securitization of mortgage loans, attaching a credit guarantee purchased from Fannie Mae, Freddie Mac, or Ginnie Mae. The produced MBS are

[7] Plugging M_t into the Euler equation (2) for c_t, together with $y_t^B = r_t - r_t^B$ and $r_t \approx 1 - E_t\left[\frac{\beta u'(C_{t+1})}{u'(C_t)}\right]$, the optimal consumption plan can be solved. We do not explore implications for consumption because the focus is on the safe asset market.

then sold to investment banks and money managers, who finance their holdings using short-term funding contracts such as repo and asset-backed commercial paper. These short-term "money-like" assets are usually held by money-market mutual funds that essentially take deposites from actual households and nonfinancial corporations among others. Therefore, banks in the model represent a broad intermediation sector that intermediates funds from a general household sector to mortgage borrowers. The safe asset holders in the model can be either the investors who hold MBS to maturity or those who use MBS holdings as collateral for financing. Although different intermediation sectors are not formally modelled, an analysis will be conducted on MBS repo market to examine the association between MBS convenience premium and collateral value.

Third, the model features one household sector (savers) lending to another household sector (mortgage borrowers) through banks. Such a setup is widely used in quantitative macro models with a housing sector, where mortgage borrowers are assumed to have a lower time discount factor than saving households and hence are less patient (see Davis and Nieuwerburgh (2015) and Piazzesi and Schneider (2016) for surveys on this literature). Similarly, in our model, mortgage borrowers are also assumed to be less patient, though for simplicity, we assume that they statically take out mortgage loans rather than solving a fully dynamic optimization problem.

Finally, we assume banks extract all the convenience premium as profit using their market power. However, in practice, a fraction of the convenience premium may be passed on to mortgage borrowers, reducing the mortgage financing cost.[8] In consequence, mortgage rate can contain a component related to convenience premium.

2.2 Model Implications for Empirical Testing

In this section, we derive implications regarding the equilibrium convenience premium and quantity of the safe assets. The main focus is on how they vary with λ_t, i.e., the level of demand for MBS relative to other safe assets. After presenting the implications, we postulate a specification for the driving forces of λ_t based on the distinct features of agency MBS.

[8]Relatedly, in the model, mortgage borrowers are rate-inelastic, reflecting their rigid demand for homes, in setting up a family, moving to a good school district, and so on. Hence, banks are the marginal agents in determining the MBS supply. However, this assumption is not essential, and the relationship between the MBS supply and convenience premium remains same if banks simply securitize any mortgage loan taken by borrowers.

2.2.1 Model Implications

First, the following proposition presents the effects of λ_t on the convenience premium and issuance of MBS.

Proposition 2. ***[Comparative statics with respect to*** λ_t***]*** *The convenience premium and supply of MBS increase but the convenience premium of Treasuries decreases, in response to higher levels of demand for MBS relative to Treasuries. Formally,* $dy_t^M/d\lambda_t > 0$, $dM_t/d\lambda_t > 0$, *and* $dy_t^B/d\lambda_t < 0$.

Intuitively, an increase of λ_t shifts the demand curve of MBS upward so both the convenience premium y_t^M and supply quantity M_t increase. This increase, however, means that the savers' demand for Treasuries decreases relatively. In consequence, the convenience premium of Treasuries y_t^B decreases because their supply is exogenously determined by the government.

In the model, in addition to λ_t that captures the demand side of MBS, the parameter γ_t also captures the demand side, though, of the aggregate liquidity holdings including both MBS and Treasuries. The following proposition captures implications of a change in γ_t, which can help differentiate these two demand-side economic forces.

Proposition 3. ***[Comparative statics with respect to*** γ_t***]*** *The convenience premiums of both MBS and Treasuries, as well as the supply of MBS, increase with the level of demand for aggregate holdings of safe assets. Formally,* $dy_t^M/d\gamma_t > 0$, $dM_t/d\gamma_t > 0$, *and* $dy_t^B/d\gamma_t > 0$. *Importantly,* $dy_t^M/d\gamma_t - dy_t^B/d\gamma_t < 0$.

Not surprisingly, an increase of γ_t shifts the demand curves of both MBS and Treasuries upward, leading to increases in the convenience premiums y_t^M and y_t^B, as well as the supply quantity M_t. Furthermore, the increase of y_t^B is larger than that of y_t^M so that $dy_t^M/d\gamma_t - dy_t^B/d\gamma_t < 0$. The reason is that banks endogenously increase the MBS supply, which dampens the increase of y_t^M, but the Treasury supply is exogenously controlled by the government so does not endogenously adjust with change in demand. The dampening effect of the increase in M_t will also affect y_t^B because MBS and Treasuries are substitutable, but it is weaker for Treasuries that provide higher liquidity services ($\lambda_t < 1$).[9] This implication

[9] In the more general case with MBS and Treasuries less perfectly substitutable, this result is strengthened because the dampening effect affects y_t^B less. For example, if Q_t is a Cobb-Douglas function of MBS and Treasuries holdings such that they are not substitutes, the dampening effect of the endogenous increase of M_t does not affect y_t^B at all.

differs from that in Proposition 2 with $dy_t^M/d\lambda_t - dy_t^B/d\lambda_t > 0$, which will be explored in empirical analysis to differentiate the two economic forces of demand, i.e., λ_t and γ_t.

Turning to the change on the supply side, the following proposition presents implications when the government adjusts Treasury supply.

Proposition 4. ***[Comparative statics with respect to** B_t**]*** *The convenience premiums of both MBS and Treasuries, as well as the supply of MBS, decrease with the level of Treasury supply. That is,* $dy_t^M/dB_t < 0$*,* $dM_t/dB_t < 0$*, and* $dy_t^B/dB_t < 0$*. Moreover,* $dy_t^M/dB_t - dy_t^B/dB_t > 0$*.*

That is, an exogenous increase of B_t shifts the demand curve of Treasuries upward, leading to a decrease in the convenience premiums y_t^B. Because of the substitutability of Treasuries to MBS, this also decreases the convenience premium of MBS y_t^M. Banks endogenously respond to the initial decrease of y_t^M by cutting the supply M_t, which dampens this decrease. Therefore, issuance of safe assets by the government crowds out the issuance of privately-produced safe assets, as in Stein (2012). In consequence, the decrease of y_t^M is less than that of y_t^B, i.e., $dy_t^M/dB_t - dy_t^B/dB_t > 0$.

Finally, to understand the safety attribute of MBS, We extend the model setup to include multiple MBS that differ in terms of the amount of liquidity service they provide to households. In particular, We add another type of MBS with quantity Z_t to the liquidity holding such that $Q_t = \lambda_t(\theta M_t + Z_t) + B_t$, where θ captures the demand for MBS M relative to MBS Z. We assume $\theta > 1$, i.e., MBS M provides more liquidity service to savers than MBS Z of the same amount. Regarding the supply of MBS Z, We assume, for simplicity, that banks' optimization problem is the same as (8) for MBS M, with the same cost function $\kappa(\cdot)$. Then the first order condition is $Z_t = \phi\left(y_t^Z\right)$.

Following the same derivations as for the case with one MBS, the equilibrium convenience premiums are given by

$$y_t^M = \lambda_t \theta \gamma_t v' \left[\lambda_t \theta \phi\left(y_t^M\right) + \lambda_t \phi\left(y_t^Z\right) + B_t\right], \tag{13}$$

and

$$y_t^Z = \lambda_t \gamma_t v' \left[\lambda_t \theta \phi\left(y_t^M\right) + \lambda_t \phi\left(y_t^Z\right) + B_t\right]. \tag{14}$$

The following proposition shows how the convenience premiums change with demand shocks to MBS.

Proposition 5. ***[Multiple MBS]*** *The convenience premiums of MBS* M *and* Z *both increase with the level of demand for MBS relative to Treasuries, after the supply responses of* *banks, and the convenience premium of MBS M that provides more liquidity service rises by a larger amount. Formally,* $dy_t^M/d\lambda_t > 0$, $dy_t^Z/d\lambda_t > 0$, *and* $dy_t^M/d\lambda_t - dy_t^Z/d\lambda_t > 0$.

The intuition is simple. An increase in the demand for MBS increases the utility savers derive from holdings of both MBS, leading to increases in their convenience premiums. The type of MBS that provides more liquidity service takes on a higher increase in the convenience premium. This implication will be explored to understand the attributes of MBS that give rise to the convenience premium of MBS. For example, the MBS guaranteed by Ginnie Mae should be of higher safety than MBS guaranteed by Fannie Mae and Freddie Mac because Ginnie Mae is explicitly backed by the U.S. Government but Fannie Mae and Freddie Mac only feature an implicit government support. Therefore, a higher increase in the convenience premium of Ginnie Mae MBS relative to Fannie Mae and Freddie Mac MBS, when the demand for all MBS increases, will point to government support as a driver of the MBS safety.

2.2.2 Tie Model Implications to Empirical Testing

To take model implications to empirical testing, we consider two types of driving forces of MBS demand. Formally, we specify λ_t as

$$\lambda_t = \lambda_t^1 + \lambda_t^2(r_t), \tag{15}$$

where the the first component λ_t^1 captures shocks to MBS demand regardless of prepayment, whereas the second component captures those related to prepayment and negatively depends on mortgage rate r_t.

The λ_t^1 component can arise from the demand for MBS related to safety of the principal value. For example, policy shocks like the liquidity coverage ratio would induce a higher demand for Ginnie Mae MBS than Fannie Mae MBS. It can also arise simply from increasing fund flows, e.g., capital flows of foreign investors into the US market (Bernanke (2005)).

The $\lambda_t^2(r_t)$ component captures prepayment-related variations in MBS demand. Its negative dependence on the mortgage rate r_t is motivated by the fact that MBS with higher mortgage rate carry higher prepayment incentive due to higher potential savings of interest expenses from prepayment. Such prepayment-related demand captures "safety" preferences that can arise from various mechanisms. As one example, we consider the valuation complexity related to prepayment. Suppose the true value of an MBS at time-t is v_t, which can be learned only with a perfect prepayment model. In practice, prepayment modeling is extremely complex, which most investors do not have enough expertise on (Eisfeldt, Lustig, and Zhang (2019) and Li and Song (2020)). Without this perfect prepayment model, the estimated value of this MBS is $v_{t,e}$ that follows a distribution with density $f(v_t, \sigma_{t,e}^2)$. The variance $\sigma_{t,e}^2$ captures the complexity of the perfect prepayment model needed, which can generate value uncertainty to any investors without perfect expertise (Caballero and Simsek (2013)) or information disadvantage to investors less relatively low expertise (Gorton and Pennacchi (1990)).

Given that an MBS of higher mortgage rate r_t carries higher prepayment incentive, we specify $\sigma_{t,e}^2 = h(r_t) \times \sigma_e^2$, where $h(\cdot)$ an increasing function of r_t. That is, the variance of the estimated MBS value consists of two components: (1) σ_e^2 that captures the generic prepayment model complexity for MBS of any mortgage rate; (2) $h(r_t)$ that positively depends on the mortgage rate r_t. In consequence, r_t operates like a "multiplier" of the generic prepayment modelling complexity (σ_e^2) in leading to the variance of the estimated MBS value.[10] In this case, we have $\lambda_t^2(r_t) = -h(r_t)\sigma_e^2$.

3 Data and Measures

In this section, we introduce data and empirical measures used in our empirical analysis.

Measures of convenience premium. To measure the MBS convenience premium, we use the spread of MBS yields relative to two benchmark yields, those of AAA rated corporate bonds that have lower safety and those of Treasury securities that have higher safety, on average. In particular, we obtain yields of Fannie Mae 30-year "production-coupon" MBSs from Barclays, adjusted for prepayment options (Gabaix, Krishnamurthy, and Vigneron (2007), Boyarchenko, Fuster, and Lucca (2019), and Song and Zhu (2019)). These are newly issued MBSs with average loan rate closest to the prevailing mortgage rate and with the largest issuance and trading activities. The yields of AAA corporate bonds are those included in the Bloomberg Barclays corporate bond total return index series. We denote the AAA-MBS yield spread as $\mathrm{s}^{AAA-FN30y}$, and the Treasury-MBS yield spread as $\mathrm{s}^{Tsy-FN30y}$.[11]

[10] The latter may still vary over time but unlikely at the monthly frequency that we focus on. From private communications with large dealer banks, their prepayment models are updated once in several years.

[11] The yield spread of MBS to Treasury securities is known as option-adjusted spread (OAS) in practice, which is equal to -$\mathrm{s}^{Tsy-FN30y}$. It is computed as the interest rate spread added to the term structure of Treasury yields such that the present value of the expected future cash flows of an MBS, after adjusting for the value of homeowners' prepayment options, equals the MBS price.

Similar to Krishnamurthy and Vissing-Jorgensen (2012), the AAA-Treasury yield spread is used as a measure of Treasury convenience premium, denoted as $\mathrm{s}^{AAA-Tsy}$.

It is worth discussing potential issues with these convenience premium measures and how we shall address them upfront. First, certain variations of $\mathrm{s}^{AAA-FN30y}$ may be specific to corporate bonds, and similarly certain variations of $\mathrm{s}^{Tsy-FN30y}$ may be specific to Treasury securities. Using both yield spreads in analysis would ensure that the results reflect variations of MBS convenience premium rather than confounding effects. In addition, we include controls for credit risk and its premium directly. Second, both the AAA yield and MBS yield correspond to bonds with durations of 7-10 years, but they may not match exactly. Similar to Krishnamurthy and Vissing-Jorgensen (2012), we shall include the slope of term structure to control for duration mismatch. Third, the prepayment model used by Barclays to adjust the MBS yield can be mis-specified, resulting in errors in the MBS yield measure. We shall conduct robustness checks using the MBS yield from other dealers and including prepayment rate as a control. Fourth, even with a correctly specified prepayment model, only the interest-rate-driven prepayment risk is accounted for, and that of non-interest-rate prepayment risk remains. However, as shown by Boyarchenko, Fuster, and Lucca (2019), this non-interest-rate component does not affect time series variations of MBS yield we focus on. Moreover, this component enters the MBS yield positively in general, so makes our convenience premium estimate more conservative on average.

The first two rows in Panel A of Table 1 report summary statistics of monthly MBS and Treasury convenience premiums (in bps) from October 1993 through December 2018. The mean MBS convenience premium is 46 bps, about half of the mean Treasury convenience premium. The time series variability is similar, both with a standard deviation of about 50 basis points. The third row reports summary statistics of Treasury-MBS yield spread, with a mean of -39 basis points and a standard deviation of 23 basis points. The top left panel of Figure 2 plots monthly series of AAA-MBS and AAA-Treasury yield spreads, which exhibit significant time series variations.

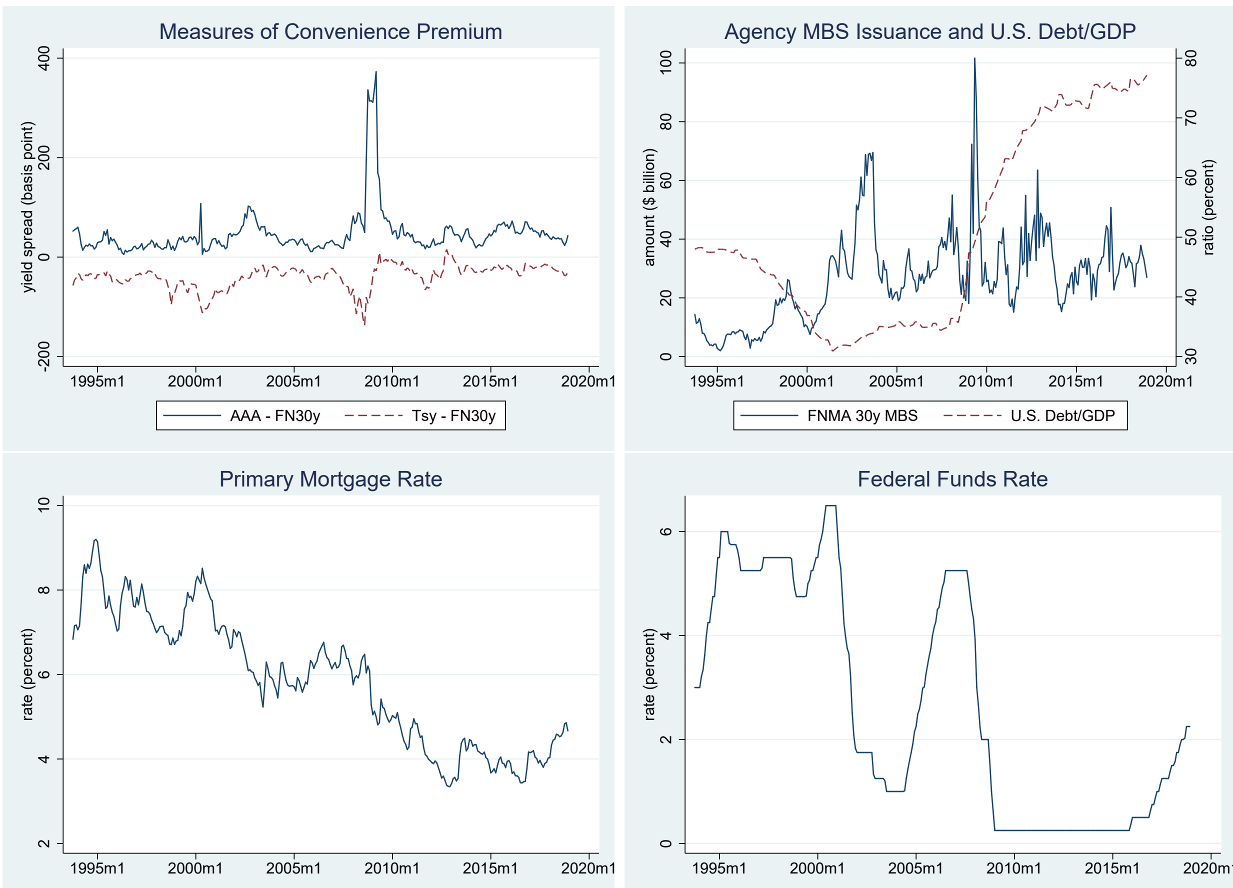
Measures of MBS supply. To measure the MBS supply, we use monthly new issuance amount of Fannie Mae 30-year production-coupon MBS. As a “flow” measure, new issuance amount suitably captures the marginal MBS supply that is endogenously determined in equilibrium in response to the demand variation as driven by λ_t. The outstanding balance, in contrast, includes all MBS that have been issued in response to historical demand and hence would bring in noise to the analysis.

Table 1: Summary of Empirical Measures

	mean	sd	min	p25	p50	p75	max
A: Yield Spread and Issuance of Fannie Mae 30-year MBS							
$s^{AAA-FN30y}$	46.47	46.96	5.47	24.65	36.41	52.28	372.63
$s^{AAA-Tsy}$	85.15	51.77	46.63	60.76	70.06	90.91	429.13
$s^{Tsy-FN30y}$	-38.68	23.18	-137.06	-47.78	-34.33	-24.27	15.49
Issuance	26.90	15.24	2.01	17.19	26.61	34.01	101.63
Log(Issuance)	3.09	0.70	0.70	2.84	3.28	3.53	4.62
B: Mortgage Rate, Federal Funds Rate, and Treasury Supply							
PMMS	5.85	1.55	3.34	4.34	5.95	7.07	9.20
FFR	2.64	2.21	0.25	0.25	1.89	5.25	6.50
Debt/GDP	50.56	16.07	30.89	35.17	46.97	69.35	77.14
Log(Debt/GDP)	3.87	0.31	3.43	3.56	3.85	4.24	4.35
C: Yield Spreads of Freddie Mac 30-year, Ginnie Mae 30-year, and Fannie Mae 15-year MBS							
$s^{AAA-FH30y}$	44.22	46.65	1.85	22.28	34.52	50.75	369.87
$s^{AAA-GN30y}$	46.38	40.43	5.84	28.19	37.62	50.68	329.42
$s^{AAA-FN15y}$	44.44	37.17	14.82	26.88	35.81	51.40	321.18
$s^{Tsy-FH30y}$	-40.94	23.64	-141.50	-50.06	-36.66	-26.52	19.31
$s^{Tsy-GN30y}$	-38.77	23.59	-158.23	-47.46	-33.20	-23.09	8.42
$s^{Tsy-FN15y}$	-40.71	25.76	-153.48	-48.68	-35.29	-23.40	0.70

Note: This table reports the mean, standard deviation (sd), 25th percentile (p25), median (p50), and 75th percentile (p75), of monthly series of empirical measures. Panel A reports the AAA-MBS yield spread for Fannie Mae 30-year production-coupon MBS ($s^{AAA-FN30y}$), the AAA-Treasury yield spread ($s^{AAA-Tsy}$), and the Treasury-MBS yield spread, all in bps, as well as the monthly new issuance of Fannie Mae 30-year production-coupon MBS (Issuance) in $bilions and its logarithm. Panel B reports the primary mortgage rate (PMMS) in percent, federal funds target rate (FFR) in percent, and U.S. debt to GDP ratio (Debt/GDP) in percent and its logarithm (Log(Debt/GDP)). Panel C reports the yield spreads of AAA corporate bonds to 30-year production-coupon MBS of Freddie Mac ($s^{AAA-FH30y}$) and Ginnie Mae ($s^{AAA-GN30y}$), as well as to 15-year production-coupon MBS of Fannie Mae ($s^{AAA-FN15y}$), all in basis points. Their yield spreads against Treasury securities, $s^{Tsy-FH30y}$, $s^{Tsy-GB30y}$, and $s^{Tsy-FN15y}$ all in bps, are also reported. The sample period is October 1993 – December 2018.

Figure 2: Monthly Series of Empirical Measures



Note: The top left panel plots monthly time series of the AAA-MBS and Treasury-MBS yield spreads, both in bps. The top right panel plots the monthly new issuance of Fannie Mae 30-year production-coupon MBS (Issuance) in $bilions and U.S. debt to GDP ratio (Debt/GDP) in percent. The bottom left panel plots monthly time series of the primary mortgage rate (PMMS) in percent, while the bottom right panel plots those of federal funds target rate (FFR) in percent. The sample period is October 1993 – December 2018.

The fourth row in Panel A of Table 1 reports summary statistics of monthly issuance amount of agency MBS (in $billions), denoted as Issuance_t, also from October 1993 through December 2018. The mean monthly issuance is about $27 billion, with a standard deviation of $15 billion. The top right panel of Figure 2 plots monthly series of MBS issuance. It undergoes an upward trend up to 2001, with an average monthly issuance of $10 billion, and stays stable afterwards around an average monthly issuance of $40 billion. The issuance shot up substantially when the federal funds rate reached record-low levels in 2002 - 2003 and 2008 - 2009. In addition, the last row in Panel A of Table 1 also provides summary statistics of Log(Issuance), similar to Krishnamurthy and Vissing-Jorgensen (2012) using the logarithm of Treasury supply.

Explanatory variables. As the measure of mortgage rate, we obtain the rate on 30-year fixed-rate mortgage loans from the Freddie Mac Primary Mortgage Market Survey (PMMS). We also obtain federal funds target rate as an alternative measure. From the first row in Panel B of Table 1, averages mortgage is 5.85%, with a standard deviation of 1.55%. From the second row in Panel B, FFR has a mean of 2.64% and a standard deviation of 2.21%. The bottom panels of Figure 2 plot monthly series of PMMS and FFR, both of which exhibit a downward trend from 1990s to 2015. Yet, there are episodes like early 2000s during which the substantial increase of FFR was only accompanied by modest increase of PMMS.

To measure the Treasury supply (B_t in the model), we obtain quarterly series of the outstanding U.S. government debt to GDP ratio from the Federal Reserve Economic Data (FRED) of the Federal Reserve Bank of St. Louis. We linearly interpolate the monthly series, and use the logarithm of debt-to-GDP ratio in empirical analysis (Nagel (2016)). Note that the debt-to-GDP ratio is a "stock" measure, different from the "flow" nature of new issuance used to measure the MBS supply. Treasury supply B_t in the model is exogenous. Accordingly, using the outstanding balance captures the effect of a change in invertors' total Treasury holdings on the equilibrium demand for MBS. The last two rows in Panel B of Table 1 report summary statistics of Debt/GDP and Log(Debt/GDP), while the top right panel of Figure 2 plots monthly series of Debt/GDP. The mean Debt/GDP ratio is 51% with a standard deviation of 16%. It decreased from about 40% to less than 20% from 1993 to 2000, stayed below 35% until 2008, and took on a substantial upward trend thereafter from less than 40% to more than 75%.

4 Main Results

In this section, we present the main results on economic drivers of the demand for MBS as safe assets.

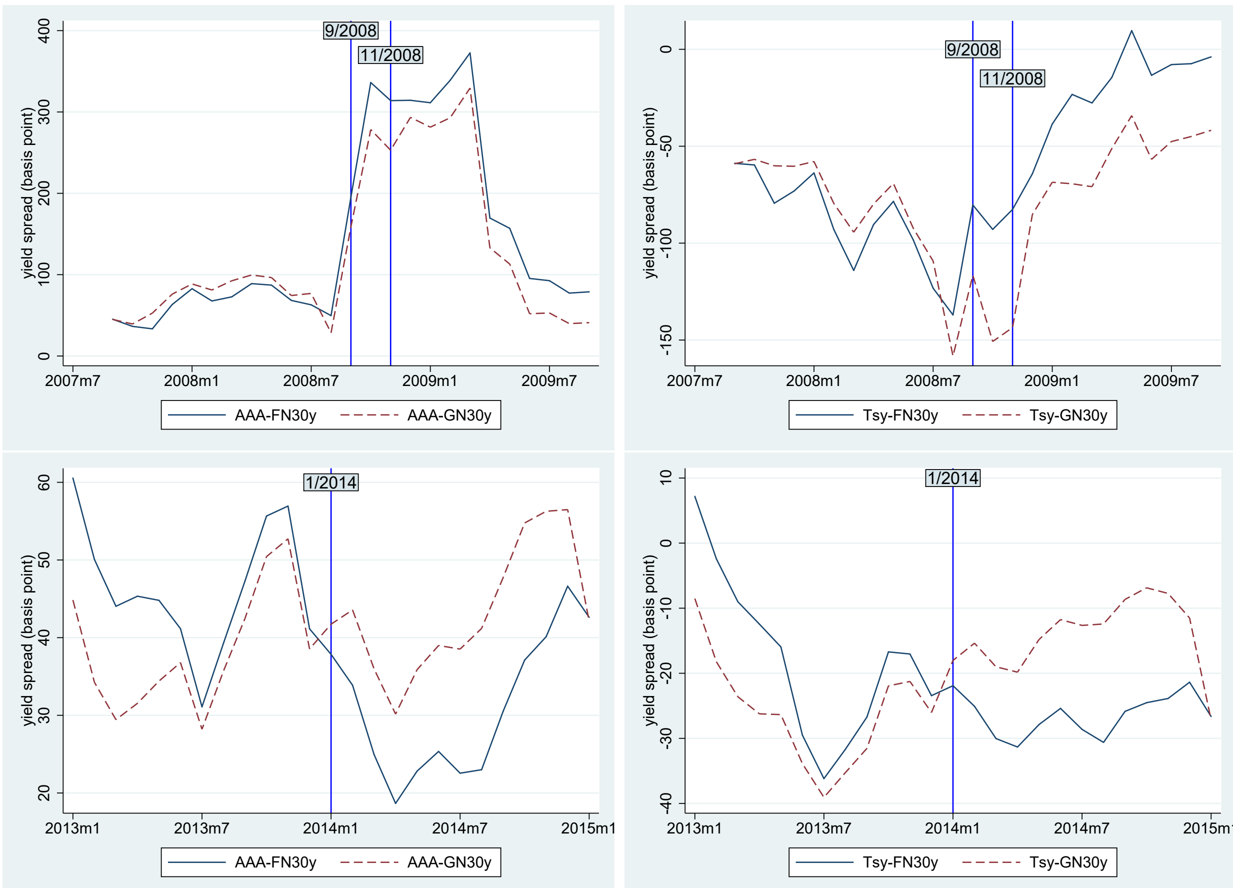
4.1 Policy Shocks to MBS Demand

We first use two policy events involving agency MBS as quasi-natural experiments for exogenous changes in MBS demand. The first is the placing of Fannie Mae (and Freddie Mac) into conservatorship announced by the Federal Housing Finance Agency (FHFA) on September 6, 2008, and the second is the progressive implementation of LCR rule since 2014. These policy shocks correspond to changes of λ_t^1 in the MBS demand specification of (15). We shall focus on their effects on convenience premium within a short time window around the policy events (the effects on MBS issuance likely take longer to materialize).

Conservatorship. Prior to the conservatorship, Fannie Mae was a private entity and believed to carry an implicit government guarantee. With the conservatorship, Fannie Mae became officially supported by the U.S. Treasury department. In contrast, Ginnie Mae has long been a wholly-owned government corporation with explicit government guarantee. Hence, the conservatorship would induce an exogenous increase in the demand for MBSs of Fannie Mae, relative to those of Ginnie Mae.

The top left panel of Figure 3 plots the yield spreads of Fannie Mae 30-year MBS (FN30y) and Ginnie Mae 30-year MBS (GN30y) against AAA corporate bonds, while the top right panel plots the yield spreads against Treasury securities. The time window is September 2007 – September 2009. We observe that the FN30y convenience premium mostly stayed lower than that of GN30y before the conservatorship but went up above afterwards, based on yields spreads to both AAA corporate bonds and Treasury securities. This pattern is consistent with an increase in demand for Fannie Mae MBS relatively. The moving of FN30y convenience premium above that of GN30y happened shortly before September 2008, likely reflecting market expectations on the rescuing of Fannie Mae by the U.S. government. The fact that the moving happened before the Fed's MBS purchases announcement on November 25, 2008 also mitigates concerns that the change was driven by policy events other than the conservatorship (see Table 2).

Figure 3: Policy Shocks and Convenience Premium Changes



Note: The top left panel plots monthly series of the AAA-FN30y and AAA-GN30y yield spreads, while the top right panel plots those of the Treasury-FN30y and Treasury-GN30y yield spreads, from September 2007 to September 2009. The bottom panels plot similar monthly series of yield spreads from from January 2013 through January 2015. The two event times in top panels are September 2008 for the conservatorship and November 2008 for the announcement of the Federal Reserve to purchase agency MBS. The event time in bottom panels is January 2014 when the LCR began to phase in.

Table 2: List of Policy Events

Year	Month	Event
2008	July	The Fed is authorized to lend to Fannie Mae and Freddie Mac if needed
	Sep	Fannie Mae and Freddie Mac are placed into conservatoship
	Nov	The Fed announced the QE1 purchase of agency MBS worth up to $500 billion
2009	Jan	QE1 purchases of agency MBSs officially started
	Mar	Expansion of the QE1 purchase of agency MBS by an additional $750 billion
2010	Mar	The QE1 purchases of agency MBSs were finished
2011	Sep	The Fed announced to reinvests cash flows from agency MBS into purchases of agency MBS
2013	Jun	The fixed-income market experienced a selloff known as "taper trantrum" since May
	Sep	The Fed announced QE3 purchases of agency MBSs at a pace of $40 billion per month
	Oct	The U.S. version of LCR was proposed
2014	Jul	SEC announced to reform the U.S. MMF industry
	Sep	The U.S. LCR rule was finalized
	Oct	QE3 purchases of agency MBSs ended, but reinvestments into agency MBSs continued
2015	Jan	Standard LCR banks were required to meet the standard at 80 percent,
2016	Jan	All LCR banks had to meet the requirement at 90 percent.
	Oct	The implmentation deadline of the SEC MMF industry reform
2017	Jan	The LCR requirement was fully phased in
	Apr	The largest globally systemically important banks began public LCR disclosures

Note: This table lists the major policy events involving agency MBS markets from 2008 to 2016.

To quantify the effect, we consider the following difference-in-difference regression:

$$s_{it}^{Tsy-MBS} = \alpha + \beta_1 \times \text{Post-Policy}_t + \beta_2 \times \text{FN30y}_i + \beta_3 \times \text{Post-Policy}_t \times \text{FN30y}_i + \text{Controls}_t + \varepsilon_{it}, \quad (16)$$

where i = FN30y or GN30y, Post-Policy$_t$ is a dummy for the months after September 2008, and FN30y$_i$ is a dummy for FN30y. Using $s^{AAA-MBS}$ would deliver the same β_3 estimate, the key parameter of our focus that captures the change in FN30y convenience premium relative to GN30y. Column (1) in Panel A of Table 3 reports the regression results for the sample of September 2007 – September 2009. We observe that PMMS is significantly negative, consistent with the baseline results in Section 4.2 using the 1993 - 2018 sample. Importantly, the estimated coefficient on the interaction term of Post-Policy$_t$ and FN30y$_i$ implies that the FN30y convenience premium increased significantly by about 49 bps relative to GN30y. Column (2) reports the regression results for the shorter window of March 2008 – March 2009 to exclude potential confounding events, and the estimated coefficient remains to be 49 bps.

One potential concern with the above estimates is that they may contain the effect of the

Table 3: Policy Shocks

	$s^{Tsy-FN30y}$		$s^{Tsy-FN30y+FNCDS}$	
	(1)	(2)	(3)	(4)
	A: Conservatorship			
	9/2007 – 9/2009	3/2008 – 3/2009	9/2007 – 9/2009	3/2008 – 3/2009
Post-Conservatorship × FN30y	48.83***	48.61***	38.06***	34.56***
	(5.62)	(4.81)	(4.44)	(3.33)
FN30y	-7.71	-6.41	41.51***	44.92***
	(-1.21)	(-0.69)	(6.35)	(4.69)
Post-Conservatorship	15.89	-26.74***	3.55	-30.16***
	(0.95)	(-4.71)	(0.26)	(-4.74)
PMMS	-47.86***	-64.81***	-53.13***	-65.48***
	(-5.20)	(-10.08)	(-6.46)	(-9.26)
VIX	-1.34***	-1.59***	-1.22***	-1.36***
	(-4.39)	(-3.19)	(-4.39)	(-2.66)
Slope	-16.35***	35.75**	-12.73***	31.35*
	(-4.11)	(2.14)	(-3.45)	(1.76)
Intercept	274.51***	244.73***	297.33***	254.83***
	(5.58)	(8.99)	(6.63)	(9.73)
N	50	26	50	26
R^2	0.84	0.87	0.89	0.92
	B: LCR			
	1/2013 – 1/2015	7/2013 – 7/2014	1/2013 – 1/2015	7/2013 – 7/2014
Post-LCR × FN30y	-20.27***	-15.14***	-16.32***	-14.97***
	(-8.79)	(-12.03)	(-6.92)	(-8.68)
FN30y	8.17***	3.88***	45.42***	44.55***
	(5.04)	(6.87)	(37.39)	(78.24)
Post-LCR	13.87***	10.05***	13.16***	9.94***
	(7.84)	(13.63)	(8.11)	(14.00)
PMMS	-85.20***	-85.65***	-76.54***	-85.76***
	(-9.54)	(-29.98)	(-9.94)	(-27.90)
VIX	0.21	0.37*	0.38	0.31
	(0.44)	(1.69)	(0.81)	(1.21)
Slope	63.61***	65.17***	59.77***	64.50***
	(8.47)	(14.74)	(8.70)	(11.82)
Intercept	157.89***	155.44***	130.26***	158.68***
	(8.55)	(11.49)	(7.93)	(11.78)
N	50	26	40	22
R^2	0.81	0.95	0.96	0.99

Note: Columns (1) - (2) in Panel A report regressions of Treasury-MBS yield spread on the dummy for FN30y, the dummy for months after the conservatorship, and their interaction term, controlling for PMMS, VIX, and slope of term structure, while columns (3) - (4) in Panel A report similar regressions of the CDS-adjusted Treasury-MBS yield spread. Panel B report regressions similar to those in Panel A, but with the dummy for months after the LCR. We compute robust t-statistics. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

conservatorship on Fannie Mae's credit worthiness. To deal with this concern, we subtract the FN30y yield by the CDS spread on Fannie Mae (FNCDS) obtained from Markit. Such adjustment is not needed for GN30y because the conservatorship does not affect the credit worthiness of Ginnie Mae. Columns (3) and (4) in Panel A of Table 3 report the regression results using the CDS-adjusted yield spread $s^{Tsy-FN30y+FNCDS}$ for the sample of September 2007 – September 2009 and of March 2008 – March 2009, respectively. The coefficients on the interaction term of Post-Policy$_t$ and FN30y$_i$ are smaller in magnitude, suggesting that the conservatorship did affect the market pricing of Fannie Mae creditworthiness. However, the increase of FN30y convenience premium relative to that of GN30y is still highly significant, around 35-38 bps.

LCR. Turning to the LCR requirement in Basel III, we exploit the difference in the haircut charged to Fannie Mae MBS and to Ginnie Mae MBS as HQLA holdings. The former is 15%, while the latter is zero, equivalent to excess reserves at central banks and Treasury securities (the haircut is 50% haircut for investment grade corporate and municipal bonds). This would induce a relative decrease in banks' demand for Fannie Mae MBS compared with Ginnie Mae MBS. The LCR has experienced progressive implementations, and we choose January 2014 as the policy event time.

The bottom left panel of Figure 3 plots the yield spreads of FN30y and GN30y against AAA corporate bonds, while the bottom right panel plots those against Treasury securities, from January 2013 through January 2015. We observe that the FN30y convenience premium mostly stayed above that of GN30y before January 2014 but went down below afterwards, consistent with a relative decrease in demand for Fannie Mae MBS. The moving of FN30y convenience premium below that of GN30y happened long before the 2016 money market fund reforms, and also after the taper tantrum over March - June 2013 (see Table 2 for major policy events again).

Columns (1) and (2) in Panel B of Table 3 report results of the regression (16) with Post-Policy$_t$ defined as the dummy for the months after January 2014, for the sample of January 2013 – January 2015 and July 2013 – July 2014, respectively. The estimated coefficients on the interaction term imply that the FN30y convenience premium decreased significantly by about 15-20 bps relative to GN30y. Columns (3) and (4) further report the regression results using the CDS-adjusted yield spreads $s^{Tsy-FN30y+FNCDS}$. The estimated coefficients on the interaction term remain little changed, especially for the shorter sample, suggesting that the LCR rule does not affect the (relative) creditworthiness of Fannie Mae and Ginnie Mae. The estimated LCR effect on convenience premium is still 15 bps.

4.2 Variations of Mortgage Rate and MBS Demand

We now study the effects of variations in investors' MBS demand related to prepayment. The baseline results document the dependence of MBS convenience premium and issuance on mortgage rate. Further results are then provided to rule out a number of alternative interpretations.

4.2.1 Mortgage Rate, Convenience Premium, and Issuance

As discussed in Section 2.2, a negative effect of mortgage rate on MBS convenience premium and issuance is expected because mortgage rate "amplifies" valuation complexity and negatively affects MBS demand λ_t. Columns (1) - (2) in Panel A of Table 4 report monthly time series regressions of $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$ on mortgage rate, respectively. We compute robust t-statistics based on Newey and West (1987) standard errors with optimal bandwidth of Andrews (1991) (these choices are followed in all the empirical analyses unless specified otherwise). Indeed, mortgage rate is negatively associated with both $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$ significantly, with t-statistics larger than 3.

Columns (3) - (4) add VIX and slope of the term structure (10-year minus 3-month) as control variables for credit risk of corporate bonds and maturity mismatch, as detailed in Section 3. Stock return volatility is highly correlated with the expected default frequency (EDF) measure of Moody's Analytics (the former is actually a key input into the computation of the latter), so including VIX in regressions controls for credit risk (Krishnamurthy and Vissing-Jorgensen (2012)). Slope of the term structure controls for potential maturity mismatch, but also helps control for risk premium because it can capture the state of business cycle. The two controls are indeed significant in affecting $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$, with the coefficient on slope of term structure being positive. The effect of VIX is positive for the former but negative for the latter (see more discussions in Section 4.2.2). Most importantly, regression coefficients on mortgage rate remain highly significant after including these two controls. Further, the coefficients become remarkably similar, -6.8 for $\mathrm{s}^{AAA-FN30y}$ and -6.5 for $\mathrm{s}^{Tsy-FN30y}$. This implies that the effect of mortgage rate on the two yield spreads is likely through its effect on MBS convenience premium, instead of through its effects specific to AAA corporate bonds or effects specific to Treasury securities.

Turning to the MBS supply, columns (5) - (6) of Table 4 report monthly time series

Table 4: Determinants of MBS Convenience Premium and Supply

	A: Effect of Mortgage Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
	$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$	$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$	Log(Issuance)	Log(Issuance)
PMMS	-5.985***	-7.960***	-6.804***	-6.534***	-0.310***	-0.319***
	(-3.086)	(-4.573)	(-2.780)	(-5.518)	(-6.421)	(-7.083)
VIX			3.690***	-1.142***		0.020***
			(3.022)	(-4.530)		(2.656)
Slope			6.617***	5.542***		0.005
			(2.723)	(3.158)		(0.072)
Intercept	81.497***	7.902	1.447	11.068	4.907***	4.561***
	(5.462)	(0.865)	(0.075)	(1.578)	(19.069)	(17.137)
N	303	303	303	303	303	303
R^2	0.039	0.283	0.489	0.446	0.465	0.515

	B: Effect of Treasury Supply		
	(1)	(2)	(3)
	$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$	Log(Issuance)
Log(Debt/GDP)	2.266	11.631*	-1.756***
	(0.168)	(1.855)	(-7.953)
PMMS	-6.488**	-4.910***	-0.564***
	(-2.478)	(-4.269)	(-16.179)
VIX	3.708***	-1.048***	0.006
	(2.935)	(-5.368)	(1.164)
Slope	6.619***	5.551***	0.003
	(2.719)	(4.349)	(0.105)
Intercept	-9.543	-45.343	13.076***
	(-0.135)	(-1.487)	(12.303)
N	303	303	303
R^2	0.489	0.457	0.790

Note: In Panel A, columns (1) - (2) report monthly time series regressions of $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$ on PMMS, respectively. Columns (3) - (4) add VIX and slope of term structure as controls. Column (5) reports regression of log MBS issuance on PMMS, and column (6) adds VIX and slope of term structure as controls. In Panel B, columns (1) - (3) report regressions of $s^{AAA-FN30y}$, $s^{Tsy-FN30y}$, and log MBS issuance on Log(Debt/GDP), together with PMMS, VIX, and slope of term structure. Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. The sample period is October 1993 – December 2018. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

regressions of log MBS issuance on mortgage rate. We observe that mortgage rate negatively affects MBS issuance significantly, with t-statistics larger than 6. The magnitude of the coefficient on mortgage remains same when including control variables.

These effects of mortgage rate are economically large. Based on estimates in columns (3) - (4), a one-standard-deviation increase in mortgage rate (1.55%) decreases the MBS convenience premium by about 11 ($\approx -6.804 * 1.55$) bps using $s^{AAA-FN30y}$ and by about 10 ($\approx -6.534 * 1.55$) bps using $s^{Tsy-FN30y}$, about 20% of their mean values (as reported in Table 1). Based on estimates in column (6), a one-standard-deviation increase in mortgage rate reduces the monthly issuance by about 50% ($\approx -0.319 * 1.55$), roughly 16% of the mean.

In addition, Panel B of Table 4 reports regressions of MBS convenience premium and issuance on Log(Debt/GDP). We observe that the effect of Treasury supply on MBS convenience premium is positive but weak both statistically and economically. A one-standard-deviation increase in Log(Debt/GDP) (0.31) increases $s^{Tsy-FN30y}$ by about only 4 ($\approx 11.631 * 0.31$) bps. The effect on MBS issuance is significant and large, however. A one-standard-deviation increase in Log(Debt/GDP) decreases monthly MBS issuance by about 50% ($\approx -1.756 * 0.31$). This strong crowding-out effect, consistent with the substitutability of MBS and Treasury security in satisfying safe asset demand, suggests that the use of Treasury supply as a monetary policy can have important consequences for housing finance.[12]

4.2.2 Alternative Interpretations

We now discuss a number of alternative interpretations for our baseline empirical results and present evidence to rule them out.

First of all, mortgage rate may proxy γ_t that governs demand for *all* safe assets, instead of λ_t that governs demand for agency MBS *relative to* other safe assets. As shown in Figure 2, mortgage rate is low in economic downturns that are usually associated with a strong broad fight-to-safety and hence high γ_t. However, as shown in Section 2.2, $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$ should depend on γ_t with opposite signs. Intuitively, this is because increasing γ_t would decrease the AAA (Treasury) yield less (more) than the MBS yield due to its lower (higher) safety. The effect of VIX as reported in Table 4 above – positive for $s^{AAA-FN30y}$ but negative for $s^{Tsy-FN30y}$ – is actually consistent with proxying for broad flight-to-safety (Nagel (2016)). In contrast, the negative dependence of both yield spreads on mortgage rate

[12]Crowding-out effects of the supply of Treasury securities as public safe assets on private safe assets like commercial paper have been documented in Krishnamurthy and Vissing-Jorgensen (2015), Greenwood, Hanson, and Stein (2015), and Stein (2012).

in Panel A of Table 4 is against interpreting mortgage rate as a proxy for γ_t in affecting MBS convenience premium.

Second, using mortgage rate as a cause for demand shift λ_t is subject to a potential endogeneity concern: an unobservable negative MBS demand shock, which decreases MBS convenience premium and issuance, can lead to a rise in mortgage rate because lower convenience premium can be passed on to mortgage borrowers. To address this concern, we use FFR as an alternative measure. As the policy instrument, the target FFR is arguably controlled by the Federal Reserve. Importantly, if the Federal Reserve does respond to the unobservable negative demand shock, FFR would be cut downward to depress increasing mortgage rate. However, from regressions of PMMS on FFR using both levels and changes reported in columns (1) - (2) of Table 5, mortgage rate is positively associated with FFR, inconsistent with an endogenous response of FFR to mortgage rate. Columns (3) - (5) then report regressions of $s^{AAA-FN30y}$, $s^{Tsy-FN30y}$, and log MBS issuance on FFR. The regression coefficients are all significantly negative, consistent with the baseline results using mortgage rate.[13] The negative dependence of both yield spreads on FFR also rules out the interpretation of FFR as a proxy for γ_t.

Third, the negative effect of mortgage rate on MBS issuance is consistent with alternative MBS-supply-driven channels. For example, high mortgage rate implies high interest expenses to mortgage borrowers, which can lead to low quantity of mortgage loans and MBS directly. That is, the causality runs from mortgage rate to MBS issuance first and then to convenience premium, rather than from mortgage rate to convenience premium first and then to MBS issuance in our MBS-demand-driven interpretation. Under the MBS-supply-driven interpretation, however, the convenience premium should depend on issuance negatively because higher supply decreases the marginal benefit of MBS holdings ($v''() < 0$ as in the model). In contrast to this prediction, regressions of MBS convenience premium measures on issuance, reported in the last two columns of Table 5, deliver significantly positive coefficients.[14]

[13] As argued in Nagel (2016), the negative correlation between FFR and Treasury supply can be large, reflecting the neutralizing effect of the Fed's monetary policy operations of target rate on the Treasury supply. To understand whether this correlation distorts the results, we regress Log(Debt/GDP) on FFR and extract the regression residual as the component of Log(Debt/GDP) orthogonal to FFR. Using this orthogonal component of Log(Debt/GDP) in regressions delivers similar results.

[14] There are other MBS-supply-driven channels. For example, households may purchase homes for reasons unrelated to mortgage rate, such as positive income shocks, employment-driven relocations, or children reaching school age. Yet, they all imply a negative dependence of MBS convenience premium on issuance, which is inconsistent with the positive dependence reported in Table 5. In fact, these channels imply that MBS issuance should not depend on mortgage rate, which is inconsistent with the significant regression coefficient of MBS issuance on mortgage rate reported in Table 4 in the first place.

Table 5: Alternative Interpretations

	PMMS		$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$	Log(Issuance)	$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Level	Change					
FFR	0.9022***	0.552***	-6.237**	-3.513**	-0.498***		
	(55.4504)	(8.033)	(-2.366)	(-2.330)	(-15.341)		
Log(Issuance)						8.372*	5.627**
						(1.871)	(2.057)
Log(Debt/GDP)			1.639	15.740	-1.640***	23.225*	27.669***
			(0.125)	(1.638)	(-7.668)	(1.848)	(4.201)
VIX	0.0002	-0.002	3.712***	-1.030***	0.007	3.681***	-1.059***
	(0.0781)	(-0.763)	(2.951)	(-4.053)	(1.268)	(2.870)	(-4.134)
Slope	0.8784***	0.602***	0.429	2.285	-0.483***	6.899***	5.835***
	(24.3165)	(12.300)	(0.123)	(1.112)	(-10.774)	(2.767)	(3.162)
Intercept	1.7598***	-0.002	-16.672	-74.733*	11.565***	-154.624**	-153.951***
	(20.0967)	(-0.217)	(-0.252)	(-1.687)	(11.500)	(-2.398)	(-5.653)
N	303	302	303	303	303	303	303
R^2	0.9762	0.506	0.492	0.439	0.771	0.482	0.434

Note: Columns (1) - (2) report monthly time series regressions of PMMS on FFR, using level and change series, respectively. Columns (3) - (5) report regressions of $s^{AAA-FN30y}$, $s^{Tsy-FN30y}$, and log MBS issuance on FFR, respectively. Columns (6) - (7) report regressions of the two yield spreads on log MBS issuance. All regressions include VIX and slope of term structure as controls, while columns (3) - (5) also include Log(Debt/GDP). Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. The sample period is October 1993–December 2018. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

4.3 Collateral Value

Safe assets are heavily used as collateral for short-term financing, e.g., in repo contracts. In consequence, the value of serving as collateral in short-term funding markets should be tied to the convenience premium of agency MBS as safe assets. In this section, we document the significant association between the collateral value of MBS and their convenience premium.

Table 6: Repo Spreads

A: Summary Statistics of repo$^{Tsy-FN30y}$				
	Mean	Sd	min	Max
	-6.13	13.16	-88.86	0.62
B: Regressions of repo$^{Tsy-FN30y}$				
s$^{Tsy-FN30y}$	0.317***			
	(3.257)			
PMMS		-4.785***		
		(-3.745)		
FFR			-4.948***	
			(-3.773)	
Log(Debt/GDP)		16.528**	15.990**	
		(1.970)	(2.002)	
VIX		-0.328*	-0.324**	
		(-1.953)	(-2.112)	
Slope		0.854	-3.806**	
		(0.949)	(-2.311)	
Intercept	3.967*	21.095***	14.561***	
	(1.650)	(3.054)	(2.757)	
N	168	168	168	
R^2	0.315	0.233	0.287	

Note: Panel A reports summary statistics of the Treasury-MBS repo spread. The first column of Panel B reports monthly time series regressions of the Treasury-MBS repo spread on yield spread, while the second and third columns report regressions of the repo spread on PMMS and FFR, respectively, together with Log(Debt/GDP), VIX, and slope of the term structure. The repo rates used are annualized overnight rates in bps. Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. The sample period is January 2005–December 2018. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

To empirically measure the collateral value of agency MBS, we obtain (annualized) overnight repo rates on the General Collateral Finance (GCF) repo platform from Depository Trust & Clearing Corporation (DTCC). We use the spread of GCF repo rates for Treasury securities and agency MBS, denoted as $\text{repo}^{Tsy-MBS}$, as the measure of MBS collateral value similar to $s^{Tsy-FN30y}$.[15] Panel A of Table 6 reports summary statistics of the repo spread from January 2005 to December 2018. The mean repo spread is -6 basis points, showing that investors prefer Treasury security to agency MBS as collateral in repo contracts.

Column (1) reports regressions of $s^{Tsy-FN30y}$ on the repo spread. The coefficient is positive and highly significant, with the repo spread increasing by 0.3 bp when the yield spread increases by one bp. The adjusted R^2 is 32%. Hence, MBS collateral value is significantly associated with convenience premium.

We further regress the repo spread on mortgage rate to see if this important economic driver of MBS convenience premium affects the repo spread likewise. From the regression results in column (2), the regression coefficient of repo spread on mortgage rate is significantly negative, consistent with regressions of $s^{Tsy-FN30y}$. Regressions of the repo spread on FFR in column (3) give similar results. Economically, a one-standard-deviation increase in PMMS (1.00) over January 2005 – December 2018 decreases the repo spread by about 5 ($\approx -4.785 * 1.00$), which is over 90% of the mean repo spread.

5 Additional Results and Robustness Checks

We provide a number of additional results and robustness checks.

5.1 Across Tenors and Agencies

So far, we have focused on determinants of MBS demand that change over time, as captured by λ_t in the model, using Fannie Mae 30-year MBS. In this section, we study potential determinants of MBS demand that are time-invariant, as captured by θ in the model. These are tenors (15-year vs 30-year) and agencies (Ginnie Mae vs Fannie Mae and Freddie Mac).

Panel C of Table 1 reports summary statistics of convenience premium measures of Freddie Mac 30-year MBS (FH30y), Ginnie Mae 30-year MBS (GN30y), and Fannie Mae 15-year MBS (FN15y). The mean yield spreads are all close to that of FN30y, about 44 to 46 bps against AAA corporate bonds and -40 to -38 bps against Treasury securities. Hence, simply comparing mean convenience premiums does not reveal whether tenor and agency are significant determinants of MBS demand.

[15] We also obtain the overnight repo rate of Treasury securities in the broad tri-party repo market from Bloomberg, and use its spread to GCF MBS repo rate as a second measure of $\text{repo}^{Tsy-MBS}$. The results are similar.

Table 7: MBS of Different Agencies and Tenors

	GN30y			FH30y			FN15y		
	$s^{AAA-GN30y}$	$s^{Tsy-GN30y}$	$s^{GN30y-FN30y}$	$s^{AAA-FH30y}$	$s^{Tsy-FH30y}$	$s^{FH30y-FN30y}$	$s^{AAA-FN15y}$	$s^{Tsy-FN15y}$	$s^{FN15y-FN30y}$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A: Regressions on PMMS									
PMMS	-5.53***	-5.26***	-1.28**	-6.98***	-6.71***	0.18	-5.28***	-5.01***	-1.52***
	(-2.68)	(-7.33)	(-2.43)	(-2.83)	(-5.39)	(0.59)	(-3.35)	(-5.82)	(-2.68)
VIX	3.02***	-1.81***	0.67***	3.64***	-1.19***	0.05*	2.76***	-2.08***	0.93***
	(2.96)	(-8.33)	(3.52)	(2.99)	(-4.53)	(1.69)	(3.17)	(-10.17)	(5.09)
Slope	4.94**	3.86***	1.68**	6.25**	5.18***	0.37*	2.22	1.14	4.40***
	(2.03)	(3.57)	(2.11)	(2.56)	(2.97)	(1.69)	(1.39)	(0.91)	(5.37)
Intercept	10.20	19.82***	-8.76**	1.95	11.57	-0.50	17.30	26.92***	-15.85***
	(0.64)	(3.40)	(-1.97)	(0.10)	(1.50)	(-0.22)	(1.26)	(4.94)	(-3.65)
N	303	303	303	303	303	303	303	303	303
R^2	0.43	0.53	0.27	0.48	0.44	0.06	0.39	0.52	0.50
B: Regressions on FFR									
FFR	-5.41***	-4.44***	-1.03**	-6.65***	-5.68***	0.21	-5.11***	-4.15***	-1.33**
	(-2.60)	(-6.91)	(-2.11)	(-2.74)	(-5.13)	(0.75)	(-3.26)	(-5.44)	(-2.50)
VIX	3.03***	-1.82***	0.66***	3.65***	-1.21***	0.05	2.77***	-2.09***	0.93***
	(2.97)	(-8.52)	(3.49)	(3.00)	(-4.64)	(1.60)	(3.18)	(-10.37)	(5.07)
Slope	-0.49	-0.35	0.72	-0.36	-0.22	0.59	-2.89	-2.75*	3.12***
	(-0.15)	(-0.30)	(0.71)	(-0.11)	(-0.12)	(1.30)	(-1.19)	(-1.90)	(3.04)
Intercept	2.44	9.21*	-11.57***	-8.71	-1.93	-0.43	9.59	16.36***	-18.72***
	(0.16)	(1.88)	(-2.81)	(-0.47)	(-0.31)	(-0.24)	(0.72)	(3.75)	(-4.91)
N	303	303	303	303	303	303	303	303	303
R^2	0.44	0.51	0.26	0.48	0.42	0.06	0.40	0.51	0.50

Note: Columns (1) - (3) of Panel A report monthly time series regressions of AAA-GN30y, Treasury-GN30y, and GN30y-FN30y yield spreads on PMMS, respectively, controlling for VIX and slope of term structure. Columns (4) - (6) of Panel A report regressions of AAA-FH30y, Treasury-FH30y, and FH30y-FN30y yield spreads on PMMS, respectively. Columns (7) - (9) of Panel A report regressions of AAA-FN15y, Treasury-15y, and FN15y-FN30y yield spreads on PMMS, respectively. Panel B report regressions to those in Panel A but on FFR. Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. The sample period is October 1993–December 2018. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

However, based on our model, the effects can be revealed in the loading of convenience premiums on the same demand driver across MBSs with different characteristics. For example, by Proposition 5, if strong government backing increases MBS demand, Ginnie Mae MBS would experience a larger increase in convenience premium with an increasing MBS demand. Hence, regressing the convenience premium of Ginnie Mae MBS on mortgage rate (as a negative MBS demand driver) should deliver a less negative coefficient. We conduct such tests on pairs of MBSs that differ in one characteristic at a time to isolate the determinant.

Columns (1) - (2) in Panel A of Table 7 report regressions of $s^{AAA-GN30y}$ and $s^{Tsy-GN30y}$ on mortgage rate, respectively, controlling for VIX and slope of the term structure. The regression coefficients on mortgage rate are significantly negative, consistent with those for FN30y. Importantly, the coefficients for GN30y (-5.53 and -5.26) are lower than those for FN30y (-6.80 and -6.53 reported in columns (3) - (4) of Panel A in Table 4). In fact, from column (3), regressing the GN30y-FN30y yield spread delivers a significantly negative coefficient. Hence, the extent of government support positively affects MBS demand. Consistently, columns (4) - (6) show that the regression coefficients on mortgage rate for FH30y are not significantly different from those for FN30y. Further, columns (6) - (9) show that the regression coefficients of the FN15y convenience premium on mortgage rate are significantly less negative than those for FN30y, implying that shorter maturity is associated with higher MBS demand.

Economically, a one-standard-deviation increase in PMMS (1.55) is associated with a decrease of 1.98 ($\approx 1.28*1.55$) bps for $s^{GN30y-FN30y}$ and of 2.36 ($\approx 1.52*1.55$) bps $s^{FN15y-GN30y}$. The regressions on FFR in Panel B of Table 7 deliver the same findings.

5.2 Prepayment Model Misspecifications

As discussed in Section 3, the measures of MBS yields are provided by Barclays, so the prepayment option adjustment is based on this dealer's proprietary prepayment model and subject to misspecification issues. In this section, we obtain measures of MBS yields from an alternative major Wall Street dealer, and show that our main results remain similar. We also control for realized prepayment rates in regressions.

The first two columns in Panel A of Table 8 report regressions of $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$ on mortgage rate, as well as Log(Debt/GDP), VIX, and slope of term structure, using the alternative dealer's MBS yields that are available from January 2000 to December 2018. The regression coefficients on mortgage rate are significantly negative, similar to the results in Table 4. The magnitudes are mainly different due to the difference in sample periods. The last two columns report regressions on FFR, which also deliver similar results.

Panel B of Table 8 reports regressions using the baseline MBS yields as in Table 4 but adding prepayment rate (obtained from the alternative dealer and available from January 2000 to December 2018) as a control variable. The coefficient on prepayment rate is negative, which is intuitive because high prepayment rate increases MBS yield. Yet, it is marginally significant at best, and does not affect the significant negative effects of mortgage rate and FFR.

5.3 Credit Risk

The yields of AAA corporate bonds contain a credit risk component, as discussed in Section 3. The MBS yields also contain a credit risk component regarding the default of Fannie Mae. In this section, we extend the CDS adjustment used in Section 4.1 over the periods of policy events to the long time series sample. We subtract the yields of AAA corporate bonds and Fannie Mae MBSs by the CDS spreads on the North American Investment Grade bond index and on Fannie Mae, respectively, both obtained from Markit.

The firs two columns of Table 9 report the regression results using the CDS-adjusted AAA-MBS yield spread, while the last two columns report those for the CDS-adjusted Treasury-MBS yield spread. We observe that the regression coefficients on mortgage rate are significantly negative, consistent with those in Table 4. The regression coefficients on FFR are also negative, though the statistical significance is slightly weak for the CDS-adjusted AAA-MBS yield. Overall, these results confirm the robustness of our results to adjustments for credit risk.

5.4 Monthly Changes

The variables used in regressions so far, including the yield spreads, mortgage rate, federal funds rate, and Treasury supply, all have persistent level series. Specifically, from the last column of Table 10, the first-order autocorrelations of the levels of these variables range from 79% to 92%. In addition to adjusting for these autocorrelations in calculating standard errors of regression estimates, as have been done, we conduct analyses using monthly changes of these variables in this section.

From the summary statistics in Table 10 on monthly changes of these variables, the first-order autocorrelation is less than 23% for $\Delta \mathrm{s}^{AAA-FN30y}$, $\Delta \mathrm{s}^{Tsy-FN30y}$, ΔLog(Issuance), and ΔPMMS, about 40% for $\Delta \mathrm{Log}(Debt/GDP)$, and about 60% for ΔFFR. These magnitudes

Table 8: Prepayment Models and Controls

	$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$	$s^{AAA-FN30y}$	$s^{Tsy-FN30y}$
A: MBS Yields from an Alternative Dealer				
PMMS	-8.120**	-8.912***		
	(-2.209)	(-4.716)		
FFR			-7.567**	-7.727***
			(-2.076)	(-4.957)
Log(Debt/GDP)	55.088***	52.335***	54.178***	51.654***
	(2.820)	(3.579)	(2.786)	(3.824)
VIX	4.712***	-1.052***	4.687***	-1.113***
	(4.017)	(-5.063)	(3.971)	(-5.549)
Slope	-3.607	0.897	-10.711*	-6.142**
	(-1.370)	(0.513)	(-1.885)	(-2.347)
Intercept	9.230	28.143***	-4.374	11.237
	(0.546)	(2.581)	(-0.300)	(1.505)
N	228	228	228	228
R^2	0.559	0.485	0.559	0.465
B: Control for Prepayment Rate				
PMMS	-7.110**	-10.191***		
	(-2.036)	(-4.520)		
FFR			-6.643*	-8.429***
			(-1.803)	(-4.389)
Prepayment Rate	-2.371*	-0.527	-2.419*	-0.963
	(-1.688)	(-0.650)	(-1.841)	(-1.331)
Log(Debt/GDP)	-32.013**	-30.946***	-32.943**	-32.620***
	(-2.267)	(-3.015)	(-2.334)	(-3.272)
VIX	4.735***	-0.975***	4.716***	-1.050***
	(3.811)	(-4.158)	(3.762)	(-4.610)
Slope	0.890	4.855***	-5.359	-2.721
	(0.335)	(2.753)	(-0.925)	(-0.871)
Intercept	5.246	28.314***	-6.420	9.239
	(0.299)	(2.891)	(-0.428)	(1.452)
N	228	228	228	228
R^2	0.575	0.568	0.576	0.545

Note: Panel A report monthly time series regressions of $s^{AAA-FN30y}$ and $s^{Tsy-FN30y}$ on PMMS (in the first two columns) and FFR (in the last two columns), while Panel B add prepayment rate as a control variable. All regressions include Log(Debt/GDP), VIX, and slope of the term structure. The option-adjusted yields of FN30y from an alternative Wall Street dealer are used to compute the yield spreads in Panel A. The prepayment rate measure used in Panel B is also from this alternative dealer, though the FN30y yields from Barclays are used to compute the yield spreads. The sample period from January 2000 to December 2018. Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

Table 9: Adjustment for Credit Risk

	$s^{AAA-FN30y-IGCDS+FNCDS}$		$s^{Tsy-FN30y+FNCDS}$	
PMMS	-23.506*		-26.923***	
	(-1.829)		(-3.942)	
FFR		-17.046		-10.659***
		(-1.604)		(-2.903)
Log(Debt/GDP)	-99.586***	-83.842***	-39.659**	6.281
	(-3.137)	(-3.011)	(-2.381)	(0.538)
VIX	4.670***	4.665***	-0.596**	-0.612**
	(5.778)	(6.010)	(-2.234)	(-1.970)
Slope	-2.022	-18.147	7.198***	-3.003
	(-0.686)	(-1.456)	(4.444)	(-0.640)
Intercept	413.814**	295.524**	290.704***	13.523
	(2.256)	(2.101)	(2.874)	(0.227)
N	123	123	144	144
R^2	0.701	0.706	0.627	0.531

Note: The first two columns report monthly time series regressions of CDS-adjusted AAA-FN30y yield spreads on PMMS and FFR, respectively, as well as Log(Debt/GDP), VIX, and slope of term structure. The last two columns report regressions of CDS-adjusted Treasury-FN30y yield spreads on PMMS and FFR, respectively. The overall sample period is from October 2003 to February 2016 for CDS-adjusted AAA-FN30y yield spreads, and from January 2002 for CDS-adjusted Treasury-FN30y yield spreads.

are substantially lower than those of the level series.

Table 10: Summary Statistics of Monthly Changes

	mean	sd	p25	p50	p75	AC(1)	AC(1) of Levels
$\Delta s^{AAA-FN30y}$	-0.0298	20.2372	-5.2997	0.3045	4.3768	0.0317	0.7887
$\Delta s^{Tsy-FN30y}$	0.2431	7.2520	-3.6783	-0.1347	4.0011	0.1649	0.8748
ΔLog(Issuance)	0.0021	0.2175	-0.1093	0.0042	0.1124	-0.1687	0.8759
ΔPMMS	-0.0074	0.1873	-0.1265	-0.0295	0.0805	0.2310	0.9129
$\Delta\text{Log}(\frac{Debt}{GDP})$	0.0016	0.0106	-0.0028	0.0001	0.0043	0.4376	0.9163
ΔFFR	-0.0025	0.1586	0.0000	0.0000	0.0000	0.6318	0.9136

Note: This table reports the mean, standard deviation (sd), 25th percentile (p25), median (p50), 75th percentile (p75), and first-order autocorrelation (AC(1)), of monthly changes in $s^{AAA-FN30y}$ (in bps), $s^{Tsy-FN30y}$ (in bps), the log of MBS issuance (in \$billion), PMMS (in percent), the log of U.S debt to GDP ratio (in percent), and FFR (in percent). The last column reports the first-order autocorrelation of the corresponding level series of each variable. The sample period is October 1993–December 2018.

Columns (1) -(3) of Table 11 report regressions of $\Delta s^{AAA-FN30y}$, $\Delta s^{Tsy-FN30y}$, and ΔLog(Issuance) on ΔPMMS, as well as the change of Log(Debt/GDP), VIX, and slope of the term structure. The regression coefficients on ΔPMMS are significantly negative, while those on $\Delta\text{Log}(Debt/GDP)$ are significantly positive for $\Delta s^{Tsy-FN30y}$ and negative for ΔLog(Issuance). These are all consistent with the baseline results in Section 4.2. Further, the results of regressions on FFR reported in columns (4) - (6) are also similar. In sum, results using series of monthly changes confirm the significant dependence of MBS convenience premium and supply on mortgage rate.[16]

5.5 Excluding the 2008 Crisis

As shown in Figure 2, the measures of convenience premium experience extremely large variations in the 2008 crisis, with AAA-MBS yield spread reaching almost 400 bps. To make sure that our results are not driven by this sample period exclusively, Table 12 reports regressions of $s^{AAA-FN30y}$, $s^{Tsy-FN30y}$, and log MBS issuance on mortgage rate (in the first three columns) and on FFR (in the last three columns) excluding the 2008 crisis period,

[16]Regressions based on monthly changes of variables also make it viable to conduct instrumental variable analysis on the Treasury supply as an exogenous driver. We follow Greenwood, Hanson, and Stein (2015) to use month dummies that capture seasonal fluctuations in tax receipts that represent plausible exogenous shocks to the T-bill supply. We also investigated using federal funds futures price as IV for ΔPMMS, but do not find a significant association between them, though the dependence of ΔFFR on federal funds futures price is significant (Kuttner (2001)).

Table 11: Regressions using Monthly Changes

	(1) $\Delta s^{AAA-FN30y}$	(2) $\Delta s^{Tsy-FN30y}$	(3) ΔLog(Issuance)	(4) $\Delta s^{AAA-FN30y}$	(5) $\Delta s^{Tsy-FN30y}$	(6) ΔLog(Issuance)
ΔPMMS	-30.544***	-15.469***	-0.119*			
	(-2.717)	(-5.053)	(-1.699)			
ΔFFR				-16.928**	-7.165**	-0.207**
				(-2.438)	(-2.136)	(-2.393)
ΔLog($\frac{Debt}{GDP}$)	8.196	94.315**	-3.943***	46.593	108.171**	-4.089***
	(0.053)	(2.295)	(-3.113)	(0.233)	(1.975)	(-3.212)
ΔVIX	2.074***	-0.669***	-0.003	2.374***	-0.756***	-0.003
	(2.633)	(-5.950)	(-0.884)	(2.731)	(-6.066)	(-0.782)
ΔSlope	12.936	6.519**	0.080	-6.769	-2.819	-0.056
	(1.301)	(2.542)	(1.246)	(-0.838)	(-1.049)	(-0.663)
Intercept	-0.237	0.082	0.008	-0.601	0.023	0.008
	(-0.289)	(0.217)	(0.738)	(-0.539)	(0.050)	(0.628)
N	302	297	303	218	213	219
R^2	0.205	0.255	0.040	0.194	0.213	0.065

Note: Columns (1) - (3) report regressions of monthly changes in $s^{AAA-FN30y}$, $s^{Tsy-FN30y}$, and log MBS issuance on monthly changes in PMMS, while columns (4) - (6) report regressions on monthly changes in FFR, together with monthly changes in Log(Debt/GDP), VIX and Slope. Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. The sample period is October 1993–December 2018. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

defined as December 2007 – June 2009 following the NBER definition of business cycles. The regression coefficients on mortgage rate and FFR are all significantly negative similar to the baseline results.

Table 12: Regressions Excluding the 2008 Crisis

	(1) $s^{AAA-FN30y}$	(2) $s^{Tsy-FN30y}$	(3) Log(Issuance)	(4) $s^{AAA-FN30y}$	(5) $s^{Tsy-FN30y}$	(6) Log(Issuance)
PMMS	-5.557***	-5.479***	-0.560***			
	(-3.671)	(-3.861)	(-16.041)			
FFR				-4.981***	-4.128***	-0.499***
				(-3.357)	(-3.227)	(-15.818)
$Log(\frac{Debt}{GDP})$	-8.138	3.821	-1.708***	-7.237	7.717	-1.606***
	(-0.962)	(0.604)	(-7.678)	(-0.837)	(1.150)	(-7.494)
VIX	0.569	-1.160***	0.010	0.581	-1.140***	0.011
	(1.335)	(-4.098)	(1.556)	(1.367)	(-3.931)	(1.539)
Slope	4.989***	5.868***	-0.003	0.132	1.992	-0.489***
	(3.586)	(3.705)	(-0.118)	(0.075)	(1.028)	(-12.041)
Intercept	82.385**	-8.978	12.803***	68.717*	-38.129	11.368***
	(2.177)	(-0.278)	(11.942)	(1.844)	(-1.165)	(11.218)
N	284	284	284	284	284	284
R^2	0.329	0.560	0.805	0.329	0.535	0.800

Note: Columns (1) - (3) report monthly time series regressions of $s^{AAA-FN30y}$, $s^{Tsy-FN30y}$, and log MBS issuance on PMMS, while columns (4) - (6) report regressions on FFR, together with Log(Debt/GDP), VIX and Slope. Robust t-statistics based on Newey and West (1987) standard errors using the optimal bandwidth of Andrews (1991) are reported in parentheses. The sample period is October 1993–December 2018, excluding the 2008 crisis period of December 2007 – June 2009. Significance levels: ** for $p < 0.01$, * for $p < 0.05$, and $^{+}$ for $p < 0.1$, where p is the p-value.

6 Conclusion

We conduct the first analysis on the economic role of agency MBS as safe assets. Our estimates show that the average MBS convenience premium is about half of that of Treasury bonds. In studying economic determinants of MBS demand, we document the importance effects of variations in MBS demand, both those regardless of and related to prepayment. We also find that MBS repo rate is significantly associated with convenience premium.

The importance of agency MBS as safe assets, as documented by this paper, offers new and broad perspectives on various issues in housing finance, monetary policies, and asset pricing. For example, the celebrated safe asset status of agency MBS should deliver important benefits to U.S. households for mortgage financing. Quantifying such benefits are important for polices on housing finance. The significant effects of mortgage rate and federal funds rate on the MBS demand suggest a convenience-premium channel of monetary policy transmission, which is distinct from the traditional interest cost channel (Boivin, Kiley, and Mishkin (2010)). Moreover, the convenience premium agency MBS receive can potentially help explain asset price movements of MBS, e.g., the time-series variation of MBS spread mainly driven by non-prepayment risk factors (Boyarchenko, Fuster, and Lucca (2019)). Overall, many economic issues based on the broad perspective of agency MBS as safe assets remain to be researched.

Appendices

A Proofs

In this section, We provide detailed proofs for propositions in Section 2.2.

Proof. of Proposition 2: Because $\kappa''(\cdot) > 0$, we have $\phi'(\cdot) > 0$. Taking derivatives of both sides of (11) with respect to λ_t, we have

$$dy_t^M/d\lambda_t = \gamma_t v' + \lambda_t \gamma v'' \cdot \left(M_t + \lambda_t \phi' dy_t^M/d\lambda_t\right).$$

This implies that

$$dy_t^M/d\lambda_t = \frac{\gamma_t v' + \lambda_t \gamma_t v'' M_t}{1 - \lambda_t^2 \gamma_t v'' \phi'} > 0,$$

because $v'(B_t + \lambda_t M_t) + v''(B_t + \lambda_t M_t)\lambda_t M_t > 0$, $v'' < 0$, and $\phi' > 0$. For equilibrium quantity, by Equation (10), we have

$$dM_t/d\lambda_t = \phi' dy_t^M/d\lambda_t > 0,$$

because $\phi' > 0$ and $dy_t^M/d\lambda_t > 0$

Finally, for the convenience premium of Treasures,

$$dy_t^B/d\lambda_t = \gamma v'' \cdot \left(M_t + \lambda_t \phi' dy_t^M/d\lambda_t\right) < 0$$

because $v''(\cdot) < 0$ and $dM_t/d\lambda_t > 0$.

□

Proof. of Proposition 3: Taking derivatives of both sides of (11) with respect to γ_t, we have

$$dy_t^M/d\gamma_t = \lambda_t v' + \lambda_t^2 \gamma_t v'' \phi' dy_t^M/d\gamma_t$$

which implies that

$$dy_t^M/d\gamma_t = \frac{\lambda_t v'}{1 - \lambda_t^2 \gamma_t v'' \phi'} > 0,$$

because $v' > 0$, $v'' < 0$, and $\phi' > 0$. For equilibrium quantity, by Equation (10), we have

$$dM_t/d\gamma_t = \phi' dy_t^M/d\gamma_t > 0$$

because $\phi' > 0$ and $dy_t^M/d\gamma_t > 0$. Furthermore,

$$\begin{aligned} dy_t^B/d\gamma_t &= v' + \gamma_t v'' \lambda_t \phi' dy_t^M/d\gamma_t \\ &= v' + \gamma_t v'' \lambda_t \phi' \frac{\lambda_t v'}{1-\lambda_t^2 \gamma_t v'' \phi'} \\ &= \frac{v'}{1-\lambda_t^2 \gamma_t v'' \phi'} > 0, \end{aligned}$$

because $v''(\cdot) < 0$ and $v' > 0$. Therefore,

$$\begin{aligned} dy_t^M/d\gamma_t - dy_t^B/d\gamma_t &= \frac{\lambda_t v'}{1-\lambda_t^2 \gamma_t v'' \phi'} - \frac{v'}{1-\lambda_t^2 \gamma_t v'' \phi'} \\ &= \frac{(\lambda_t - 1)\, v'}{1-\lambda_t^2 \gamma_t v'' \phi'} < 0, \end{aligned}$$

because $\lambda_t < 1$.

□

Proof. of Proposition 4: Taking derivatives of both sides of (11) with respect to B_t, we have

$$dy_t^M/dB_t = \lambda_t \gamma_t v'' \cdot \left(1 + \lambda_t \phi' dy_t^M/dB_t\right).$$

This implies that

$$dy_t^M/dB_t = \frac{\lambda_t \gamma_t v''}{1-\lambda_t^2 \gamma v'' \phi'} < 0,$$

because $v'' < 0$ and $\phi' > 0$. Moreover, we have

$$dM_t/dB_t = \phi' dy_t^M/dB_t < 0,$$

because $\phi' > 0$ and $dy_t^M/dB_t < 0$. Finally, by (12),

$$\begin{aligned} dy_t^B/dB_t &= \gamma_t v'' \cdot \left(1 + \lambda_t \phi' dy_t^M/dB_t\right) \\ &= \gamma_t v'' \cdot \left(1 + \lambda_t \phi' \frac{\lambda_t \gamma_t v''}{1-\lambda_t^2 \gamma_t v'' \phi'}\right) \\ &= \frac{\gamma_t v''}{1-\lambda_t^2 \gamma_t v'' \phi'} < 0 \end{aligned}$$

because $v'' < 0$. Therefore,

$$\begin{aligned} dy_t^M/dB_t - dy_t^B/dB_t &= \frac{\lambda_t \gamma_t v''}{1-\lambda_t^2 \gamma_t v'' \phi'} - \frac{\gamma_t v''}{1-\lambda_t^2 \gamma_t v'' \phi'} \\ &= \frac{(\lambda_t - 1)\gamma_t v''}{1-\lambda_t^2 \gamma_t v'' \phi'} > 0 \end{aligned}$$

because $v'' < 0$ and $\lambda_t < 1$..

□

Proof. of Proposition 5: Taking take derivatives on both sides of (13) with respect to λ_t, we have

$$dy_t^M/d\lambda_t = \theta\gamma_t v' + \theta\lambda_t\gamma_t v''(\theta M_t + Z_t) + \theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right) dy_t^M/d\lambda_t + \theta\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right) dy_t^Z/d\lambda_t$$

Similarly, taking derivatives with respect to θ on both sides of (14), we have

$$dy_t^Z/d\lambda_t = \gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t) + \lambda_t^2\gamma_t v''\theta\phi'\left(y_t^M\right) dy_t^M/d\lambda_t + \lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right) dy_t^Z/d\lambda_t.$$

Therefore,

$$\begin{aligned} \left[1-\theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)\right] dy_t^M/d\lambda_t - \left[\theta\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)\right] dy_t^Z/d\lambda_t &= \theta\left[\gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t)\right] \\ \left[\lambda_t^2\gamma_t v''\theta\phi'\left(y_t^M\right)\right] dy_t^M/d\lambda_t + \left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right) - 1\right] dy_t^Z/d\lambda_t &= -\left[\gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t)\right]. \end{aligned}$$

Solving these two equations, we have

$$\begin{aligned} dy_t^M/d\lambda_t &= \frac{\theta\left[\gamma_t v' + \lambda_t\gamma_t v''\cdot(\theta M_t + Z_t)\right]\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right) - 1\right]}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)-1\right]\left[1-\theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)\right] + \theta^2\lambda_t^4\gamma_t^2\left(v''\right)^2\phi'\left(y_t^Z\right)\phi'\left(y_t^M\right)} \\ &\quad - \frac{\left[\gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t)\right]\left[\theta\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)\right]}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)-1\right]\left[1-\theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)\right] + \theta^2\lambda_t^4\gamma_t^2\left(v''\right)^2\phi'\left(y_t^Z\right)\phi'\left(y_t^M\right)} \\ &= \frac{-\theta\left[\gamma v' + \lambda_t\gamma v''\cdot(\theta M_t + Z_t)\right]}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)-1\right] + \theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)}, \end{aligned}$$

and

$$\begin{aligned} & dy_t^Z/d\lambda_t \\ = & \frac{\theta\left[\gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t)\right]\left[-\lambda_t^2\gamma_t v''\theta\phi'\left(y_t^M\right)\right]}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)-1\right]\left[1-\theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)\right] + \theta^2\lambda_t^4\gamma_t^2\left(v''\right)^2\phi'\left(y_t^Z\right)\phi'\left(y_t^M\right)} \\ & - \frac{\left[\gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t)\right]\left[1-\theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)\right]}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right)-1\right]\left[1-\theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)\right] + \theta^2\lambda_t^4\gamma_t^2\left(v''\right)^2\phi'\left(y_t^Z\right)\phi'\left(y_t^M\right)} \\ = & \frac{-\left[\gamma_t v' + \lambda_t\gamma_t v''(\theta M_t + Z_t)\right]}{\lambda_t^2\gamma_t v''\left[\phi'\left(y_t^Z\right) + \theta^2\phi'\left(y_t^M\right)\right] - 1}. \end{aligned}$$

Therefore,

$$
\begin{aligned}
dy_t^M/d\lambda_t - dy_t^Z/d\lambda_t &= \frac{-\theta\left[\gamma_t v' + \lambda_t\gamma_t v''\cdot(\theta M_t + Z_t)\right] + \left[\gamma_t v' + \lambda_t\gamma_t v''\left(\theta M_t + Z_t\right)\right]}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right) - 1\right] + \lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)} \\
&= \frac{\left[\gamma_t v' + \lambda_t\gamma_t v''\left(\theta M_t + Z_t\right)\right](1-\theta)}{\left[\lambda_t^2\gamma_t v''\phi'\left(y_t^Z\right) - 1\right] + \theta^2\lambda_t^2\gamma_t v''\phi'\left(y_t^M\right)} > 0,
\end{aligned}
$$

because the denominator is positive, $v'(Q_t) + v''(Q_t)\left[\lambda_t\left(\theta M_t + Z_t\right)\right] > 0$, and $\theta > 1$.

□

B Data

We provide details on the data sources and construction of all variables used in the paper. Unless discussed explicitly otherwise, the available sample period is October 1993 - December 2018.

Yields of agency MBS, corporate bonds, and Treasuries. Data for agency MBS yields, including option-adjusted spreads (OAS) relative to Treasury yields, of 30-year production-coupon MBS guaranteed by Fannie Mae (FN30y), Freddie Mac (FH30y), and Ginnie Mae (GN30y) and 15-year production-coupon MBS guaranteed by Fannie Mae, are computed based on corresponding TBA prices and obtained from a major Wall Street dealer. The yield spread of AAA rated corporate bonds to maturity-matched Treasury securities is based on the corporate bond total return index series from the same dealer. Alternative OAS series of 30-year production-coupon Fannie Mae MBS are obtained from another major Wall Street dealer. The yield spread of AAA corporate bonds to Treasuries is used as $s^{AAA-Tsy}$ and the OAS of agency MBS to Treasuries is used as $s^{MBS-Tsy}$, whereas the difference between is used as $s^{AAA-MBS}$, where $MBS \in \{FN30y, FH30y, GN30y, FN15y\}$. All these yield spreads are available at the daily frequency, and monthly measures are constructed as the average of daily observations over a month.

Monthly issuance amount of agency MBS. The monthly new issuance amount of 30-year production-coupon Fannie Mae MBS is obtained from disclosure reports of Fannie Mae, historically collected by eMBS. The issuance amount series are available at the monthly frequency.

Primary and secondary mortgage market rates and federal funds rate. The primary mortgage rate for 30-year fixed-rate mortgage loans is obtained from the Freddie Mac primary mortgage market survey. It is available at the weekly frequency and the monthly measure is constructed as the average of weekly observations over a month. The current-coupon rate is the par coupon rate of a synthetic par TBA contract obtained by interpolating TBA prices trading near par. Its daily series are obtained from Barclays, and the average of daily observations over a month is used as its monthly measure. Daily series of federal funds target rate are from the Federal Reserve Economic Data (FRED) maintained by Federal Reserve Bank of St. Louis, with point target rate prior to December 16, 2008 and target range afterwards for which the mid-point is used. The monthly measure of federal funds target rate is constructed as the average of daily observations over a month.

Forecasts of agency MBS prepayment rates. The daily series of one-month prepayment rate forecast of 30-year production-coupon Fannie Mae MBS are obtained from the Wall Street dealer who also provides alternative OAS series. The prepayment rate computed is the single monthly mortality rate equal to the fraction of the scheduled balance (=total beginning balance - scheduled principal payment) at the beginning of the month that is predicted to be prepaid during that month. Its relation with the so-called annualized conditional prepayment rate (CPR) is that CPR=1-(1-SMM)*12. The monthly measure is constructed as the average of daily series over a month.

Repo rates. The repo rates of agency MBS and Treasury securities in General Collateral Finance (GCF) overnight repo contracts are from the series of GCF Repo Index provided by the Depository Trust & Clearing Corporation (DTCC).[17] The GCF repo platform is maintained by the Fixed Income Clearing Corporation (FICC) that itself is a wholly owned subsidiary of DTCC. The daily repo rate in the series is the average interest rate across repo transactions, weighted by volume, within a day, available from January 2005. We use the average of daily observations over a month as the monthly measure.

Treasury securities supply. Data on the outstanding U.S. government debt to GDP ratio is from the FRED, specifically, the seasonally adjusted quarterly series of the "Federal Debt Held by the Public as Percent of Gross Domestic Product" (FYGFGDQ188S), first constructed by the Federal Reserve Bank of St. Louis in October 2012 based on data from the U.S. Office of Management and Budget. Similar to Nagel (2016), We linearly interpolate the quarterly series to obtain monthly measures.

Control variables. The VIX series are obtained from the Chicago Board Options Exchange (CBOE), whereas Treasury yields are those constructed by Gurkaynak, Sack, and Wright (2007) based on which slope of term structure is measured as the difference between the 10-year and 3-month rates, similar to Krishnamurthy and Vissing-Jorgensen (2012). For both variables, monthly values are calculated as the average of daily observations in a month.

Repo outstanding balance. Outstanding balances of tri-party repo, with collateral assets as Treasury securities, agency debt, asset-backed securities, private-label collateralized mortgage obligations, corporate bonds, municipal bonds, and money market instruments, are obtained from the Federal Reserve Bank of New York.[18] They are calculated based on snapshots of the market on the seventh business day of each month using data from the two tri-party repo clearing banks, Bank of New York Mellon and JP Morgan Chase.

[17]The series can be downloaded at `http://www.dtcc.com/charts/dtcc-gcf-repo-index#download`.

[18]The data are disclosed to the public at `https://www.newyorkfed.org/data-and-statistics/data-visualization/tri-party-repo`.

References

Andrews, D. (1991). Heteroskedasticity and autocorrelation consistent covariance matrix estimation. *Econometrica 59*, 817–858.

Bank for International Settlements (2013). Basel iii: The liquidity coverage ratio and liquidity risk monitoring tools. *Basel Committee on Banking Supervision*.

Bansal, R. and W. J. Coleman (1996). A monetary explanation of the equity premium, term premium, and risk-free rate puzzles. *Journal of Political Economy 104*(6), 1135–1171.

Bansal, R., W. J. Coleman, and C. Lundblad (2011). Endogenous liquidity supply. *working paper*.

Bartolini, L., S. Hilton, S. Sundaresan, and C. Tonetti (2011). Collateral values by asset class: Evidence from primary securities dealers. *Review of Financial Studies 24(1)*, 248–278.

Baumol, W. J. (1952). The transactions demand for cash: An inventory theoretic approach. *The Quarterly Journal of Economics 66*(4), 545–556.

Bernanke, B. S. (2005). The global saving glut and the U.S. current account deficit. Speech 77, Board of Governors of the Federal Reserve System (U.S.).

Bessembinder, H., W. Maxwell, and K. Venkataraman (2013). Trading activity and transaction costs in structured credit products. *Financial Analysts Journal 69(6)*, 55–68.

Boivin, J., M. T. Kiley, and F. S. Mishkin (2010). Chapter 8 - how has the monetary transmission mechanism evolved over time? Volume 3 of *Handbook of Monetary Economics*, pp. 369 – 422. Elsevier.

Boyarchenko, N., A. Fuster, and D. O. Lucca (2019). Understanding Mortgage Spreads. *The Review of Financial Studies 32*(10), 3799–3850.

Brock, W. A. (1974). Money and growth: The case of long run perfect foresight. *International Economic Review 15*(3), 750–777.

Caballero, R. (2006). On the macroeconomics of asset shortages. The Role of Money - Money and Monetary Policy in the Twenty-First Century. Frankfurt: European Central Bank.

Caballero, R. and E. Farhi (2017). The Safety Trap. *The Review of Economic Studies 85*(1), 223–274.

Caballero, R. J., E. Farhi, and P.-O. Gourinchas (2008). An equilibrium model of "global imbalances" and low interest rates. *American Economic Review 98*(1), 358–93.

Caballero, R. J., E. Farhi, and P.-O. Gourinchas (2017). The safe assets shortage conundrum. *Journal of Economic Perspectives 31*(3), 29–46.

Caballero, R. J. and A. Simsek (2013). Fire sales in a model of complexity. *The Journal of Finance 68*(6), 2549–2587.

Carlin, B., F. Longstaff, and K. Matoba (2014). Disagreement and asset prices. *Journal of Financial Economics 114*, 226–238.

Carlson, M. and D. C. Wheelock (2018). Near-money premiums, monetary policy, and the integration of money markets: Lessons from deregulation. *Journal of Financial Intermediation 33*, 16 – 32.

Carlstrom, C. T. and T. S. Fuerst (2001). Timing and real indeterminacy in monetary models. *Journal of Monetary Economics 47*(2), 285 – 298.

Chen, J., H. Liu, A. Sarkar, and Z. Song (2020). Cash-forward arbitrage and dealer capital in mbs markets: Covid-19 and beyond ves. *Federal Reserve Bank of New York Staff Reports* (933).

Chernov, M., B. Dunn, and F. Longstaff (2018). Macroeconomic-driven prepayment risk and the valuation of mortgage-backed securities. *Review of Financial Studies 31*(3), 1132–1183.

Clower, R. (1967). A reconsideration of the microfoundations of monetary theory. *Economic Inquiry 6*(1), 1–8.

Dang, T. V., G. Gorton, and B. Holmström (2015). Ignorance, debt and financial crises. *working paper*.

Davis, M. A. and S. V. Nieuwerburgh (2015). Chapter 12 - housing, finance, and the macroeconomy. In G. Duranton, J. V. Henderson, and W. C. Strange (Eds.), *Handbook of Regional and Urban Economics*, Volume 5 of *Handbook of Regional and Urban Economics*, pp. 753 – 811. Elsevier.

Diep, P., A. Eisfeldt, and S. Richardson (2017). The cross section of mbs returns. *Working Paper*.

Downing, C., D. Jaffee, and N. Wallace (2009). Is the market for mortgage backed securities a market for lemons? *Review of Financial Studies 22–7*, 2457–2494.

Du, W., J. Im, and J. Schreger (2018). The u.s. treasury premium. *Journal of International Economics 112*, 167 – 181.

Duarte, J., F. Longstaff, and F. Yu (2007). Risk and return in fixed income arbitrage: Nickels in front of a steamroller? *Review of Financial Studies 20*(3), 769–811.

Duffee, G. R. (1996). Idiosyncratic variation of treasury bill yields. *The Journal of Finance 51*(2), 527–551.

Eisfeldt, A., H. Lustig, and L. Zhang (2019). Complex asset markets. *working paper*.

Farhi, E. and M. Maggiori (2017). A Model of the International Monetary System*. *The Quarterly Journal of Economics 133*(1), 295–355.

Feenstra, R. C. (1986). Functional equivalence between liquidity costs and the utility of money. *Journal of Monetary Economics 17*(2), 271 – 291.

Fleckenstein, M. and F. Longstaff (2018). Floating rate money? the stability premium in treasury floating rate notes. *NBER Working Paper* (25216).

Fusari, N., W. Li, H. Liu, and Z. Song (2020). Asset pricing with cohort-based trading in mbs markets. *Working Paper*.

Gabaix, X., A. Krishnamurthy, and O. Vigneron (2007). Limits of arbitrage: Theory and evidence from the mortgage-backed securities market. *Journal of Finance 2*, 557–595.

Gao, P., P. Schultz, and Z. Song (2017). Liquidity in a market for unique assets: Specified pool and tba trading in the mortgage backed securities market. *Journal of Finance 72-3*, 1119–1170.

Gao, P., P. Schultz, and Z. Song (2018). Trading methods and trading costs for agency mortgage backed securities. *Journal of Investment Management 16*, 29–46.

Gorton, G. (2017). The history and economics of safe assets. *Annual Review of Economics 9*(1), 547–586.

Gorton, G., S. Lewellen, and A. Metrick (2012). The safe-asset share. *The American Economic Review 102*(3), 101–106.

Gorton, G. and G. Ordoñz (2014). Collateral crises. *American Economic Review 104*(2), 343–78.

Gorton, G. and G. Pennacchi (1990). Financial intermediaries and liquidity creation. *The Journal of Finance 45*(1), 49–71.

Greenwood, R., S. G. Hanson, and J. C. Stein (2015). A comparative-advantage approach to government debt maturity. *The Journal of Finance 70*(4), 1683–1722.

Gurkaynak, R., B. Sack, and J. Wright (2007). The u.s. treasury yield curve: 1961 to the present. *Journal of Monetary Economics 54(8)*, 2291–2304.

Hansen, S. (2014). Mortgage convexity. *Journal of Financial Economics 113-2*, 270–299.

He, Z., A. Krishnamurthy, and K. Milbradt (2019). A model of safe asset determination. *American Economic Review 109*(4), 1230–62.

He, Z., S. Nagel, and Z. Song (2020). Treasury inconvenience yields during the covid-19 crisis. *NBER Working Papers* (27416).

Ihrig, J., E. Kim, C. M. Vojtech, and G. C. Weinbach (2019). How have banks been managing the composition of high-quality liquid assets? *Federal Reserve Bank of St. Louis Review Third Quarter*, 177–201.

Jiang, Z., A. Krishnamurthy, and H. Lustig (2019a). Dollar safety and the global financial cycle. *Stanford University Graduate School of Business Research Paper No. 19-16*.

Jiang, Z., A. Krishnamurthy, and H. Lustig (2019b). Foreign safe asset demand and the dollar exchange rate. *Stanford University Graduate School of Business Research Paper No. 18-16*.

Kacperczyk, M., C. Pérignon, and G. Vuillemey (2019). The private production of safe assets. Technical report.

Kiyotaki, N. and R. Wright (1989). On money as a medium of exchange. *Journal of Political Economy 97*(4), 927–954.

Krishnamurthy, A. and A. Vissing-Jorgensen (2012). The aggregate demand for treasury debt. *Journal of Political Economy 120*(2), 233–267.

Krishnamurthy, A. and A. Vissing-Jorgensen (2015). The impact of treasury supply on financial sector lending and stability. *Journal of Financial Economics 118*(3), 571 – 600.

Kuttner, K. N. (2001). Monetary policy surprises and interest rates: Evidence from the fed funds futures market. *Journal of Monetary Economics 47*(3), 523 – 544.

Lenel, M., M. Piazzesi, and M. Schneider (2019). The short rate disconnect in a monetary economy. *Journal of Monetary Economics 106*, 59 – 77.

Li, W. and Z. Song (2019). Asset heterogeneity, market fragmentation, and quasi-consolidated trading. *working paper, Johns Hopkins Carey Business School*.

Li, W. and Z. Song (2020). Expertise, information, and dealer-intermediated otc markets. *working paper, Johns Hopkins Carey Business School*.

Longstaff, F. (2004). The flight-to-liquidity premium in u.s. treasury bond prices. *The Journal of Business 77*(3), 511–526.

Lucas, R. (1980). Equilibrium in a pure currency economy. *In Models of monetary economies, ed. J.H. Karaken and N. Wallace Federal Reserve Bank of Minnesota*, 131–145.

Maggiori, M. (2017). Financial intermediation, international risk sharing, and reserve currencies. *American Economic Review 107*(10), 3038–71.

Nagel, S. (2016). The liquidity premium of near-money assets. *The Quarterly Journal of Economics 131*(4), 1927–1971.

Newey, W. and K. West (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica 55*(3), 703–708.

Nothaft, F. E., J. E. Pearce, and S. Stevanovic (2002). Debt spreads between gses and other corporations. *Journal of Real Estate Finance and Economics 25*, 151–172.

Piazzesi, M. and M. Schneider (2016). Chapter 19 - housing and macroeconomics. Volume 2 of *Handbook of Macroeconomics*, pp. 1547 – 1640. Elsevier.

Scharfstein, D. and A. Sunderam (2017). Market power in mortgage lending and the transmission of monetary policy. *working paper*.

Schultz, P. and Z. Song (2019). Transparency and dealer networks: Evidence from the initiation of post-trade reporting in the mortgage backed security market. *Journal of Financial Economics 133*, 113–133.

Sidrauski, M. (1967). Rational choice and patterns of growth in a monetary economy. *The American Economic Review 57*(2), 534–544.

Song, Z. and H. Zhu (2019). Mortgage Dollar Roll. *The Review of Financial Studies 32*(8), 2955–2996.

Stein, J. C. (2012, 01). Monetary Policy as Financial Stability Regulation. *The Quarterly Journal of Economics 127*(1), 57–95.

Sunderam, A. (2014). Money Creation and the Shadow Banking System. *The Review of Financial Studies 28*(4), 939–977.

Tobin, J. (1956). The interest-elasticity of transactions demand for cash. *The Review of Economics and Statistics 38*(3), 241–247.

Walsh, C. (2017). *Monetary Theory and Policy*. Monetary Theory and Policy / Carl E. Walsh. MIT Press.

Xie, L. (2012). The seasons of money: Abs/mbs issuance and the convenience yield. Technical report, Yale University.