Serve to Securitise: Mortgage Securitisation, Servicing and Foreclosures*

John C.F. Kuong

INSEAD

Jing Zeng

Frankfurt School of Finance and Management

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Abstract

How does securitisation distort foreclosure decision of non-performing mortgages? Why do mortgage servicers, who decide to foreclose or to renegotiate delinquent mortgages, seem to be given biased incentives? What role do they play in securitisation? To address these questions, we develop a model in which an impatient, informed mortgage pool owner (a bank) designs and sells a mortgage-backed security to uninformed investors, and chooses the servicing arrangement which affects the subsequent decision to foreclose or modify delinquent mortgages. By contracting with a third-party servicer, the bank is able to effectively commit to a foreclosure policy that optimally trades off the ex ante cost of securitisation under asymmetric information against the ex post cost of inefficient foreclosure. We show that securitisation leads to excessive (insufficient) foreclosures in a bad state if the mortgage pool is of low (high) quality. The servicer's incentives are thus *endogenously biased*. Our model generates novel predictions regarding foreclosure rate and mortgage servicing contract that are consistent with various empirical findings about the subprime mortgage crisis in the United States.

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Email: john.kuong@insead.edu; jing.zeng@fs.de

1 Introduction

The wave of mortgage foreclosures in the aftermath of the subprime mortgage crisis in the United States has raised concerns from the general public and policy makers.[1] Reports and empirical studies have argued that foreclosures often result in significant losses for both the lenders and the borrowers, and impose substantial negative externalities to the broader society.[2] In response to the unfolding foreclosure crisis started in 2008, the U.S. government has developed the Home Affordable Modification Program, a large-scale intervention to incentivise mortgage renegotiation instead of foreclosure.[3]

Recent studies about the subprime mortgage crisis have suggested that securitisation and the biased incentives of mortgage servicers, who have the discretion to foreclose or to renegotiate a mortgage when it becomes non-performing (delinquent), could contribute to the severity of the foreclosure crisis. For instance, Piskorski et al. (2010) and Agarwal et al. (2011a) show that mortgages in a securitised pool are more likely to be foreclosed than otherwise similar mortgages on bank portfolios. Thompson (2009) analyses the compensation structure of mortgage servicers and concludes that their legal and financial incentives bias them towards foreclosure instead of mortgage modification, even when foreclosure is expected to be more costly than renegotiation.[4]

Three questions follow naturally from the empirical findings. i) How does securitisation affect the decision to foreclose or to renegotiate a delinquent mortgage? ii) What is the role played by these third-party mortgage servicers? And, iii) if servicers' biased incentives have caused excessive foreclosures, why are such compensation contracts written in the first place? This paper studies the *causal* relationship between securitisation and foreclosure policy, highlights the benefits of third-party servicing, and characterises mortgage servicers' optimal contract.

We develop a model of mortgage-backed securitisation which incorporates three

[1] According to a recent report by RealtyTrac (2015), there are more than 14 millions US properties with foreclosure filings from 2008-2014.

[2] See for example Pennington-Cross (2006) for a survey on the deadweight loss on foreclosure. Using data from 1987 to 2009 in Massachusetts, Campbell et al. (2011) estimate foreclosure discounts as large as 27 percent on average

[3] HAMP provides direct monetary incentives to mortgage servicers for each successfully renegotiated delinquent mortgage. For a detailed description and an empirical evaluation of HAMP, see Agarwal et al. (2012)

[4] See also Krueger (2014) for a empirical survey of mortgage servicers' compensation contracts.

critical elements of the industry: (1) the servicing arrangement of the loans, (2) the security design problem in securitisation under asymmetric information, and (3) the foreclosure decision when delinquency occurs. Given the key friction, namely the asymmetric information between the securitiser and the outside investors, we analyse the implications for the choice of in-house versus third-party servicing by the securitisers, and the subsequent foreclosure decision of delinquent mortgages.

Mortgage-backed securitisation is modelled as a liquidity-based security design problem à la DeMarzo and Duffie (1999) with an *endogenous* foreclosure decision after the securities are issued (or retained). A mortgage pool owner (henceforth 'securitiser') desires to raise cash by selling securities backed by the mortgages to outside investors. After the MBS are issued, however, an aggregate shock might happen, causing some mortgages to become non-performing. The securitiser must decide whether to modify or to foreclose the delinquent mortgages. These two decisions will affect the final cash flow differently: if a mortgage is modified (forbearance), the full repayment is only recovered with some probability due to the exposure of borrowers' (re-)default risk and the aggregate risk in the economy (e.g. future house prices); in contrast foreclosing a mortgage and selling the underlying property immediately at a distressed price limits such risk exposures and generates a more stable cash flow.

When the securitiser has private information regarding the recovery probability of the delinquent mortgages, she chooses to issue a senior security, or debt, to the outside investors and retains the junior tranche to signal her positive information as in DeMarzo and Duffie (1999) and DeMarzo (2005).[5] However, since the foreclosure policy affects the riskiness of the mortgage pool cash flow, the securitisation process interacts with the equilibrium foreclosure policy.

In particular, the servicing arrangement of in the securitisation process has implications for the incentives for foreclosure. A loan originator can securitise the mortgage pool with service performed in-house, or sell the pool to a specialist securitiser while remaining as a third-party servicer under a servicing contract.[6] If

[5]Using a sample of RMBS from the pre-crisis period, Begley and Purnanandam (2013) find evidence of equity-tranche retention being used as signal of unobserved pool quality. Consistent with our result, they find lower foreclosure rate for deals with a higher level of equity tranche.

[6]According to the 2014 10-K report by Fannie Mae, "[g]enerally, the servicing of the mortgage loans that are held in our retained mortgage portfolio or that back our Fannie Mae MBS is performance by mortgage servicers on our behalf. Typically, the lenders who sell single-family

the securitiser services the mortgage in-house, she tends to grant excessive forbearance. This is because given her retained equity tranche, she benefits from riskier cash flows, creating an incentive to forbear instead of foreclose.

The first result of this paper is that, contracting with a third-party servicer improves the efficiency of securitisation under asymmetric information. An important function performed by mortgage servicers is the decision of forbearance versus foreclosure.[7] The separation of servicing right from cash flow right allows the securitiser to effectively commit to an *ex ante optimal* foreclosure policy that is *ex post inefficient*, by providing an incentive contract for the third-party servicer to implement the desired foreclosure policy. The model therefore addresses the role played by third-party mortgage servicers in the securitisation industry. This is inline with the view of Thompson (2009), who argues that the rise of the servicing industry is a by-product of securitisation.

Next, we turn to the main result of the paper – how securitisation distorts foreclosure policy in equilibrium. We show that the equilibrium foreclosure policy with a third-party servicer exhibits a two-sided distortion relative the full information (also the first best) benchmark. Specifically, in a bad economic state, there is excessive foreclosure if the underlying mortgage pool is of low quality, but there is insufficient foreclosure if the mortgage pool is of high quality. This result implies that, conditional on a bad aggregate state with high delinquency, securitisation amplifies the effect of unobservable asset quality on the equilibrium foreclosure rate.

The intuition of the above result is as follows. The equilibrium foreclosure policy trades off the ex ante cost of securitisation under asymmetric information against the ex post cost of inefficient foreclosure. In order to reduce the expected signalling cost of retaining junior securities, the securitiser, before receiving the private information, designs servicing contracts so that a third-party servicer implements foreclosure policy that discourages the low type (the securitiser with a mortgage pool of low recovery probability) from mimicking the high type. The low type's mimicking payoff comprises the proceeds from selling the debt claim at the high

mortgage loans to us service these loans for us."

[7]The servicer performs duties including collecting the payments, forwarding the interest and principle to the lenders, and negotiating new terms if the debt is not being paid back, or supervising the foreclosure process.

type's price and her valuation of the retained cash flow. As such, by marginally foreclosing more for the low type, the retained junior tranche values less because it is convex in the final cash flow and foreclosure reduces cash flow risk. Similarly insufficient foreclosures for the high-type increases cash flow risk and reduces the value of the concave debt claim.

Finally, the model predicts that, since the securitiser contracts with a third-party servicer to implement the optimal foreclosure policy discussed above, the servicers are provided with endogenously biased incentives. For mortgage pools of low quality, the compensation to the servicer is designed to lean towards foreclosure. This implements the optimal foreclosure policy which would appear to be excessive *ex post*, namely, the *ex post* foreclosure may result in a loss to the investors. This is evident in the past financial crisis. For example, Levitin (2009) estimates that lenders lose approximately 50% of their investment in a foreclosure situation.

Related Literature

This paper belongs to the growing body of literature on the incentive problems associated with mortgage securitisation. Various studies argue that securitisation relaxes the *ex-ante* lending standards. Keys et al. (2010, 2012), using evidence from securitised subprime loans, show that the ease of securitisation reduces lenders' incentives to carefully screen the mortgage borrowers and that mortgages with higher likelihood to be securitised have higher default rates. Mian and Sufi (2009) find that securitisation of subprime loans is associated with credit expansion and, as a result, counties with a high proportion of subprime mortgages face a larger number of defaults. Elul (2011) also finds securitised prime loans have a higher default rates than otherwise comparable portfolio loans. Chemla and Hennessy (2014) and Vanasco (2014) theoretically study how securitisation concern affects ex ante loan originators' screening effort. Our work complements this literature by studying the decision of ex post mortgage foreclosures in relation to securitisation.

Our paper also relates to the study of optimal loan modification and foreclosure policy. Wang et al. (2002) show that when a lender (bank) has a high screening cost to ascertain whether a borrower is in distress, it could be optimal for the bank to randomly reject loan workout requests to deter the non-distressed borrower from opportunistically applying for a loan modification. Riddiough and Wyatt (1994) study the case in which the lender's foreclosure cost is private information and the borrowers will infer this cost from past loan foreclosure decisions and consequently decide their default decision and concession request. The lender thus may costly foreclose many loans today to reduce future expected default and loan modification costs. Gertner and Scharfstein (1991) focus on the free-riding problem among multiple creditors and show that when the cost of debt concessions is private but the benefit is shared, a creditor's incentive to grant concessions to a distressed firm is reduced. While the literature typically finds that the frictions lead to excessive foreclosure, this paper argues that securitisation can be another important factor affecting foreclosure decisions, and the distortion can go either way.

Closely related to our paper, Mooradian and Pichler (2014) also study the role of servicers in the mortgage-backed securitisation industry. The authors argue that the servicers need to be provided with incentives to exert effort to gather information following a loan default, in order to offer loan renegotiation efficiently. The authors then study the implications of such servicer moral hazard on mortgage pool diversification. In contrast, our model focuses on the securitisation problem under asymmetric information for a mortgage pool of given quality, and investigate the effect of servicing arrangement and the subsequent foreclosure decision.

Finally, while this paper is the first to formalise the role played by foreclosure and servicing contracts in mortgage-backed securitisation in a model of asymmetric information, several empirical studies identify securitisation as being an important impediment for efficient renegotiation following delinquency, e.g. Agarwal et al. (2011a); Piskorski et al. (2010); Zhang (2011). Particularly related to our model are the empirical findings of Agarwal et al. (2011b). The authors find that the incentives of servicers present an impediment to loss mitigation of delinquent mortgages and attribute this to the holdup problem posed by dispersed investors of the senior tranche when the servicers hold the junior tranche. Our model provides a theoretical argument for distortions in the foreclosure decision of securitised mortgages and rationalising the biased incentives of mortgage servicers.

2 Model setup

This section sets up the model and comments on the assumptions which are central to the model.

There are four dates: 0, 1, 2 and 3. The model's participants consist of two banks and a continuum of outside investors. All agents are risk neutral. The outside investors are are deep pocketed and competitive. The banks are impatient and have a discount factor $\delta < 1$ between $t = 1$ and $t = 3$. This follows the assumption of DeMarzo and Duffie (1999) and can be interpreted as a bank's incentive to raise capital by securitising part of their long term assets as the banks have access to some positive return investment opportunities. There is no discounting for the outside investors.

Mortgage pool

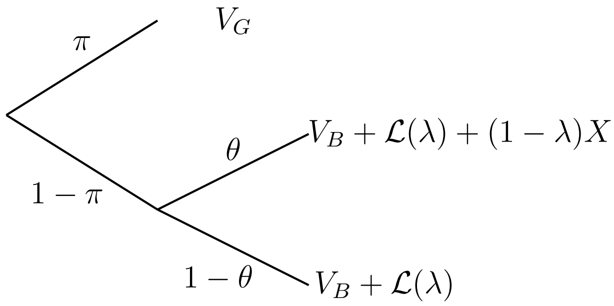
The underlying asset in our model is a pool of a continuum of ex ante identical mortgages that pays off at $t = 3$. We abstract from the ex ante selection issues of the mortgage pool, which have been studied by previous literature, to focus on the foreclosures of the mortgages when they become delinquent, as detailed below.

The mortgage performance is influenced by the state of the economy, realised at $t = 2$, which affects the ability for the home owners to repay. With probability π, the economy is in a good state (G) and no loans default. In state G, the value of the mortgage pool is V_G. With probability $1 - \pi$, the economy is in a bad state (B) and a fixed portion of the mortgages becomes delinquent. This can be interpreted as a well diversified portfolio with only a systemic component of default risk. We normalise the measure of the delinquent mortgages in the pool to 1.The remaining mortgages continue to repay and have an exogenous value of $V_B < V_G$.

Because mortgage defaults only occur in the bad state, we will henceforth focus primarily on the sequence of events after a realisation of the bad state, to study the effect of securitisation on the foreclosure of delinquent mortgages. When a mortgage becomes delinquent at $t = 2$, it can be foreclosed or granted forbearance. In case of foreclosure, the collateral property is repossessed and sold for a liquidation proceed to outside investors. In case of forbearance, the fixed mortgage repayment of value X is resumed with probability θ; otherwise the loans are worthless. For simplicity, we assume that the repayments of all delinquent mortgages are perfectly correlated. It can be interpreted to capture the aggregate nature in the risk of the mortgages. To simply analysis, we further assume that $V_G \geq V_B + X$, so that the value of a mortgage in the good state at least as high as in a bad state, even if all delinquent mortgages resume payments.

Denote $\lambda \in [0, 1]$ the fraction of delinquent mortgages foreclosed, and $\mathcal{L}(\lambda)$ the total liquidation proceed from repossessed properties. The overall cash flow from mortgage pool at $t = 3$ is then $V + \mathcal{L}(\lambda) + (1-\lambda)X$ with probability θ, and $V + \mathcal{L}(\lambda)$ with probability $(1 - \theta)$, as illustrated in Fig 1.

Figure 1: Mortgage pool cash flow



We abstract from modelling the market for distressed properties. However, we make the following two assumptions regarding the the liquidation proceed function $\mathcal{L}(\lambda)$, to ensure an interior optimal foreclosure policy in the first best case. First, the marginal liquidation value of the mortgage is below the full repayment value of the mortgage $\frac{\partial \mathcal{L}(\lambda)}{\partial \lambda} < X$ for $\lambda > 0$. Intuitively, there are costs associated with liquidation a mortgage, due to, for example, heterogeneous renovation and repair costs associated with investing in distressed property, as well as other outstanding liabilities such as unpaid fees and taxes. Secondly, $\mathcal{L}(\lambda)$ is increasing and concave in $\lambda \in [0, 1]$. The decreasing marginal liquidation value of the foreclosed loans could be due to either scarce capital or scarce expertise in making the renovation needed to realise the value of the properties.

Loan sale and servicing contract

At $t = 0$, one bank ("originator") is endowed with the pool of mortgage described before. We henceforth refer to the originator as "he". He also has private information regarding the recovery rate of the delinquent mortgages $\theta \in \{\theta_H, \theta_L\}$, where $\theta = \theta_H$ with probability γ. The assumption that the private information only concerns the credit risk of the delinquent mortgages is to simplify analysis and is not central to the model. Nevertheless, one interpretation could be that there is generally less data on delinquent loans, making it more difficult to assess the recovery rate of such borrowers by investors outside of the originating bank.

The other bank can approach the originator with the intention to acquire the beneficial rights to the mortgage cash flows for securitisation. After the transaction, the initial originator does not retain any claim to the cash flows, but remains a "third-party servicer" of the mortgages for a fee to be paid by the second bank ("securitiser"), henceforth referred to as "she".[8] The servicer performs duties including collecting the payments, forwarding the interest and principle to the lender(s), and negotiating new terms if the debt is not being paid back, or supervising the foreclosure process.[9]

Because the second bank is uninformed about the recovery rate of the delinquent mortgage in the pool at $t = 0$, she faces a screening problem and makes a take-it-or-leave-it offer of a menu of two separating, servicing contracts $\{(\alpha_i, \beta_i, \tau_i)\}_{i \in \{H,L\}}$ to the originator. Each of the contracts specifies the payments to the third-party servicer, including a percentage α_i of the forbearance cash flow to be paid at $t = 3$, a percentage $\alpha_i \beta_i$ of the foreclosure cash flow to be paid at $t = 3$, and a flat transfer τ_i to be paid at $t = 1$. Therefore β_i captures the servicer's relative incentive to foreclose a delinquent loan as compared to granting forbearance. While the form of the contract is common knowledge, the specific contract is verifiable in court but not observable to the outside investors. This assumption simplifies analysis and is

[8]Practically, the servicer need not be the originator but they are often the party as the skill set required to perform both functions are similar. There is, however, a secondary market for the transfer of servicing rights through a security called Mortgage Servicing Rights (MSR).

[9]In practice, it is plausible that there are specialisation and economics of scale benefits for one group of banks to act as securitisers (e.g. investment banks) and another to focus on originating and servicing mortgages (e.g. mortgage lenders). However, our model does not rely on this assumption. As it will become clear later in the model, we emphasise the importance of the separation of mortgages securitisation and servicing.

consistent with industry practice.

Given his private information regarding θ, the originator either accepts one of the two servicing contracts on offer and becomes a third-party servicer, or declines the offer. Without loss of generality, denote $i = H$ the contract chosen by an originator with θ_H , and $i = L$ that chosen by an originator with θ_L (the two contracts can be identical). If the loan sale goes through, the originator remains as a third-party servicer, while the second bank becomes the securitiser of the mortgage pool. If the originator declines the offer, or if he receives no offer, he retains both the cash flow rights and the servicing rights. He then securitises the mortgage pool and services the mortgages on his own (in-house servicing).

Assume that the originator incurs a transaction cost of $\kappa \geq 0$ if he agrees to be a third-party servicer in the process of securitisation. This cost does not play a significant role in our model, but only affects the willingness for the originator to sell the mortgage pool to the securitiser. It can be interpreted as covering the legal and administrative costs associated with contracting a third-party servicer.

Securitisation

At $t = 1$, the bank who owns the cash flow rights of the mortgage pool then designs a security that depends on the cash flow of the mortgage pool at $t = 3$, and sells it to outside investors. The securitiser retains the residual cash flow from the mortgage pool after paying off the investors. We will henceforth refer to the security as the mortgage-backed securities (MBS). Notice that depending on whether there has been a mortgage pool sale, there are two scenarios. If the mortgage pool has been transferred from the originator to the second bank, the latter is the securitiser (she) and the mortgage is securitised with third-party servicing. If the originator keeps the mortgage pool, he securitises it with in-house servicing.

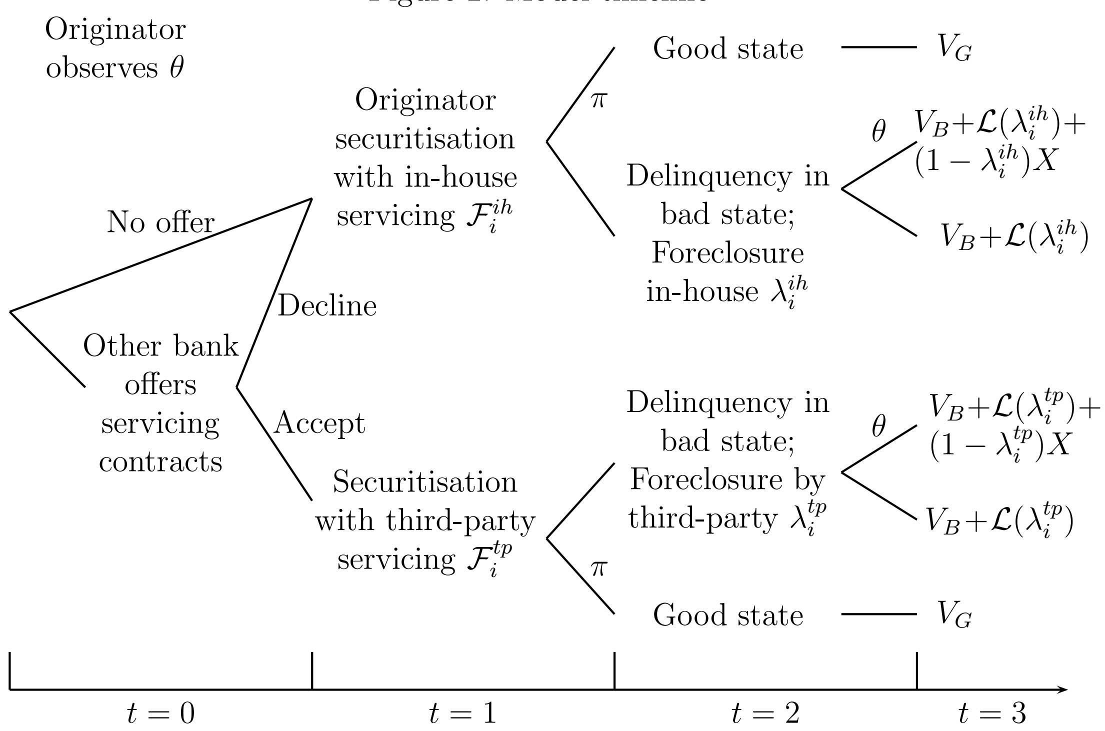
Regardless of the identity of the securitiser, the process is as follows. The securitiser offers a security $\mathcal{F}_i$ given his or her private information $i \in \{H, L\}$ regarding the recovery probability of the mortgage pool. The security $\mathcal{F}_i$ is contracted on the cash flows, specifying payments to the MBS investors for each realisation of the cash flow. Observing the security on offer, the competitive investors form a belief $\hat{\theta}$ regarding the private information of the issuer, and bids the price of the security p to its fair value, taking the foreclosure policy in equilibrium as given. We denote the case with third-party servicing with superscript tp, and the case with in-house servicing withs superscript ih.

We restrict our attention to only monotonic security payoffs. That is, a higher realisation of the mortgage pool cash flow should leave both the outside investors and the securitiser a (weakly) higher payoff.[10]

Time line and the equilibrium concept

To summarise, the timeline of the model is as in Figure 2.

Figure 2: Model timeline



The equilibrium concept in this model is the perfect Bayesian equilibrium (PBE). Formally, a PBE consists of a menu of servicing contracts, the acceptance decision of the servicing contract by the originator, the security issued by the securitiser, the

[10]Although this implies some loss of generality, it is not uncommon in the security design literature, e.g. Innes (1990) and Nachman and Noe (1994). One potential justification provided by DeMarzo and Duffie (1999) is that, the issuer has the incentive to contribute additional funds to the assets if the security payoff is not increasing in the cash flow. Similarly, the issuers has the incentive to abscond from the mortgage pool if the security leaves the issuer a payoff that is not increasing in the cash flow. If such actions cannot be observed, the monotonicity assumption is without loss of generality.

foreclosure policy, the price of the security issued, and a system of beliefs such that 1) the choices made by the two banks maximise their respective objective function, given the equilibrium choices of the other agent and the equilibrium beliefs, and 2) the beliefs are rational given the equilibrium choices of the agents and are formed using Bayes' rule (whenever applicable).

As there can be multiple equilibria in games of asymmetric information, we restrict attention to the case where $\gamma < \frac{U_H^{ih} - U_L^{ih}}{U_H^{FB} - U_L^{FB}}$, where the U_H^{FB}, U_L^{FB} are specified in Section 3, and U_H^{ih}, U_L^{ih} are specified in Section 4.2. In this case, there exists a unique equilibrium, which coincides with the least cost separating equilibrium. Intuitively, when γ is low, the expected payoff to a high type securitiser is low. The securitiser therefore prefers a separating equilibrium.

3 First best and the full information benchmarks

In this section we first characterise the first best foreclosure policy. We then analyse the equilibrium under full information, and show that the first best is achieved by the full information equilibrium.

The first best foreclosure policy maximises the value of the mortgage pool

$$\lambda_i^{FB} = \arg \max_{\lambda_i \in [0,1]} \pi V_G + (1 - \pi)[V_B + \mathcal{L}(\lambda_i) + (1 - \lambda_i)\theta_i X] \tag{1}$$

The solution is characterised by the first order condition that $\frac{\partial \mathcal{L}(\lambda_i^{FB})}{\partial \lambda_i} = \theta_i X$ for $i \in \{H, L\}$. That is, since the marginal value obtained from foreclosure is decreasing with the fraction of foreclosed loans, the first best level of foreclosure is determined such that the the margin value from foreclosure is equal to the expected recovery value given forbearance.

We now characterise the equilibrium under full information. Firstly consider the optimal security issued in the securitisation process at $t = 1$. Since any retention of the cash flows by the securitiser incurs a liquidity discount, it is optimal for the security issued to be a full equity pass through security to the investors, since all securitise are fairly priced given full information. Secondly, given that the entire cash flow is securitised, the securitiser at $t = 2$ is indifferent between all foreclosure policies. As a tie break convention, we focus on the Pareto dominating equilibrium, in which the securitiser chooses the foreclosure policy that maximises the value of the mortgage pool.

The following proposition thus summarises the full information benchmark results. All proofs are in Appendix unless stated otherwise.

Proposition 1. *In the full information benchmark, the originator securitises the mortgage pool by issuing a pass through equity security backed by the cash flows, and chooses the first best foreclosure policy* $(\lambda_H^{FB}, \lambda_L^{FB})$*, where* $\lambda_H^{FB} < \lambda_L^{FB}$*.*

Notice that the first best foreclosure policy is achieved in the full information benchmark. Therefore any inefficiency in the foreclosure policy discussed in the subsequent sections are due to the asymmetric information problem between the securitiser and the outside investors.

In the full information equilibrium, a high type securitiser forecloses a smaller fraction of delinquent mortgages and obtains less liquidation proceed than a low type, $\lambda_H^{FB} < \lambda_L^{FB}$ and $\mathcal{L}_H^{FB} < \mathcal{L}_L^{FB}$. This is because the high-quality mortgage pool has a higher recovery probability and the high-type securitiser is therefore less inclined towards foreclosure.

Moreover, the originator should securitise the mortgage pool himself in the first best benchmark, so as to avoid the transaction cost $\kappa \geq 0$ of selling his mortgage pool to the securitiser. In Section 4 we will show that there is a role for securitisation with third-party servicing, when there is asymmetric information in the securitisation process.

4 Equilibrium with asymmetric information

In this section we characterise the equilibrium with asymmetric information. We start by establishing the properties of the optimal security issued by the securitiser in equilibrium. We then characterise the sub-games of securitisation with in-house servicing and third-party servicing respectively, and finally consider the optimal servicing contracts to offer in equilibrium.

4.1 The optimal security under asymmetric information

At $t = 1$, the securitiser with private information θ designs and issues an MBS security backed by the cash flow of the mortgage pool. In this section we study the design of the MBS given a set of beliefs regarding the foreclosure policy at $t = 2$, denoted $\hat{\lambda}_i$, $i \in \{H, L\}$. This section's result does not depend on the nature of the servicing arrangement.

First, notice that in a separating equilibrium, the low type securitiser always receives the fair price on the security issued. Therefore the securitiser maximises expected payoff by selling the entire cash flow from the mortgage pool to outside investors. There is no distortion in the form of inefficient retention for the low type. Given the foreclosure policy $\hat{\lambda}_L$, denote $U_L(\hat{\lambda}_L)$ the maximum payoff to a low type securitiser. In particular, we have

$$U_L(\hat{\lambda_L}) = \pi V_G + (1 - \pi)[V_B + \mathcal{L}(\hat{\lambda_L}) + (1 - \hat{\lambda_L})\theta_L X] \tag{2}$$

Next, we consider the security issued by a high type securitiser in the least cost separating equilibrium. Since the security issued by a low type is a full pass through equity, we suppress the type subscript in the notation and refer to the security issued by the high type securitiser as $\mathcal{F}$, which maps the realisation of the mortgage pool cash flows to a set of payoffs to the outside investors, as summarised in Table 1.

Table 1: Payoffs of the security issued by the high type

Realisation of cash flow	Security payoff $\mathcal{F}$
$c_1 \equiv V_G$	f_1
$c_2 \equiv V_B + \mathcal{L}(\lambda_H) + (1 - \lambda_H)X$	f_2
$c_3 \equiv V_B + \mathcal{L}(\lambda_L) + (1 - \lambda_L)X$	f_3
$c_4 \equiv V_B + \mathcal{L}(\lambda_L)$	f_4
$c_5 \equiv V_B + \mathcal{L}(\lambda_H)$	f_5

Importantly, the cash flows are ranked in descending order in Table 1, if and only if $\lambda_H \leq \lambda_L$. We will assume that this is the case in this section. But it will be verified that indeed it is the case in equilibrium in the following sections. In particular, the first best foreclosure policies are indeed such that $\lambda_H^{FB} < \lambda_L^{FB}$ as given in Proposition 1.

In the least cost separating equilibrium, for a given foreclosure policy $\{\hat{\lambda}_H, \hat{\lambda}_L\}$, the high type securitiser simply maximises the proceed from securitisation in order to minimise the liquidity discount. That is, the optimal security for the high type securitiser is given by

$$\begin{aligned}
&\max_{\mathcal{F}} && p(\mathcal{F}) \\
s.t. \quad &(MC) && p(\mathcal{F}) = \pi f_1 + (1-\pi)[\theta_H f_2 + (1-\theta_H) f_5] \\
&(LL) && f_j \leq c_j \; \forall \; j \in \{1,2,3,4,5\} \\
&(IC) && U_L(\hat{\lambda}_L) \geq p(\mathcal{F}) + \delta\pi(c_1 - f_1) \\
& && \qquad +\delta(1-\pi)[\theta_L(c_3 - f_3) + (1-\theta_L)(c_4 - f_4)] \\
&(MNO) && f_1 \geq f_2 \geq f_3 \geq f_4 \geq f_5 \geq 0 \\
&(MNI) && c_1 - f_1 \geq c_2 - f_2 \geq c_3 - f_3 \geq c_4 - f_4 \geq c_5 - f_5 \geq 0
\end{aligned} \tag{3}$$

where (MC) is the market clearing condition that the market believes that the issuer of the security $\mathcal{F}$ is of the high type, (LL) is the limited liability condition for each cash flow realisation, (IC) is the incentive compatibility constraint for the low type not to mimic the security issued by the high type, (MMO) is the outside investors' monotonicity constraint, and (MNI) is the insider residual claim's monotonicity constraint.

The following property for the optimal security issued by the high type securitiser is crucial for the mechanism for the paper.

Proposition 2. *For $\hat{\lambda}_H \leq \hat{\lambda}_L$, the high type securitiser's optimal security's payoff conditional on the bad state resembles that of a debt security. Specifically, there exists a threshold $\bar{c} \in [V_B + \mathcal{L}(\hat{\lambda}_L), V_B + \mathcal{L}(\hat{\lambda}_H) + (1-\hat{\lambda}_H)X]$ such that the payoff of the security is*

$$f_j = \begin{cases} c_j, & \text{if } c_j < \bar{c} \\ \bar{c}, & \text{if } c_j \geq \bar{c} \end{cases} \quad \forall \; j \in \{2,3,4,5\} \tag{4}$$

This result is consistent with the literature on the pecking order of outside financing, e.g. Myers (1984) under asymmetric information. However, due to the discrete nature of the cash flows in our model, the intuition is less standard. Most importantly, since the margin foreclosure value is always (weakly) less than the full recovery value of the delinquent mortgage $\frac{\partial \mathcal{L}(\lambda)}{\partial \lambda} \leq X$, foreclosure reduces the total cash flow from the mortgage pool when the delinquent mortgages recover. This suggests that, when the high type has a lower foreclosure rate than the low type $\hat{\lambda}_H \leq \hat{\lambda}_L$, the high type enjoys greater upside potential when the bad state arises $V_B + \mathcal{L}(\hat{\lambda}_H) + (1 - \hat{\lambda}_H)X > V_B + \mathcal{L}(\hat{\lambda}_L) + (1 - \hat{\lambda}_L)X$.[11] Combined with the fact that the high type has a higher probability of recovery, the optimal security issued by the high type while preventing mimicking by the low type is one that resembles a debt security in the bad state.

Since our analysis focuses on the securitiser's foreclosure decision following mortgage delinquency, the payoff of the security in the good state without default is irrelevant. However, the payoff to the security in the good state can be higher than the threshold $\bar{c}$. Since both types have the same probability of achieving the good state, there is no information asymmetry in the good state and the result security optimally pays off more in the good state. This is in line with the results established by Fulghieri et al. (2014), that if the information asymmetry is reduced in the upside, the optimal security may not be a standard debt.[12]

4.2 Securitisation with in-house servicing

In this section we consider the equilibrium foreclosure policy in the sub-game of securitisation with in-house servicing. At $t = 2$, the originator-securitiser makes the foreclosure decision to maximise his retained cash flow give his type i and the security issued at $t = 1$.

For a low type securitiser, since he securitises a full pass-through equity security, he retains no cash flow. Assume in this case that he makes the first best foreclosure decision to maximise the value of the mortgage pool, $\lambda_L^{ih} = \lambda_L^{FB}$. The payoff to a low type originator-securitiser is therefore equal to $U_L^{ih} \equiv U(\lambda_L^{FB})$.

[11] Readers might notice that while foreclosure reduces the upside cash flow, it also increases the down side cash flow when the delinquent mortgages do not repay. Therefore $\hat{\lambda}_H \leq \hat{\lambda}_L$ also implies that $V_B + \mathcal{L}(\hat{\lambda}_H) + (1 - \hat{\lambda}_H)X < V_B + \mathcal{L}(\hat{\lambda}_L)$. However, since the high type has a lower probability of receiving this low cash flow, we show in the appendix that the optimal security indeed resembles debt condition on the bad state.

[12] The optimal security in our setting can be interpreted as a debt whose face value is reduced when a bad state with mortgage defaults is realised. In practise, since default and foreclosures lead to early repayment of the loans to the MBS holder, the effective nominal repayment is indeed reduced because of interest payment write downs.

The high type securitiser maximises his residual cash flow given an optimal security issued at $t = 1$

$$\max_{\lambda_H \in [0,1]} \quad \pi(V_G - f_1) + (1-\pi)\left[\theta_H(V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)X - f_2) \right.$$
$$\left. + (1-\theta_H)(V_B + \mathcal{L}(\lambda_H) - f_5)\right]$$
$$s.t. \quad \mathcal{F} \text{ is given by Eq. 3, and } \hat{\lambda}_L = \lambda_L^{ih} \tag{5}$$

Since Proposition 2 implies that $f_2 \geq V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)X$ and $f_5 = V_B + \mathcal{L}(\lambda_H)$, the optimal foreclosure policy for the high type securitiser maximises $V_B + \mathcal{L}(\lambda_H) + (1-\theta_H)X$. That is, he chooses zero foreclosure $\lambda_H^{ih} = 0$ as $\mathcal{L}'(0) = X$. The following proposition summarises the equilibrium foreclosure policy under in-house servicing.

Proposition 3. *If the originator declines the offer and securitises the mortgage pool with in-house servicing, the equilibrium foreclosure policy is given by* $(\lambda_H^{ih}, \lambda_L^{ih}) = (0, \lambda_L^{FB})$. *That is, there is excessive forbearance if the mortgage pool is of high quality.*

The intuition behind this proposition is similar to the classic conflict of interests between equity holders and creditors inside a financially distressed firm. As the optimal security issued by the high-type securitiser resembles a debt in the bad state, his retained security is a levered equity. Foreclosure tends to reduce the riskiness in the mortgage pool cash flow and accrues all the proceeds to the creditors if the mortgage pool does not recover. Therefore the high-type securitiser with in-house servicing chooses zero foreclosure rate in a risk-shifting attempt.

Given the ex post optimal foreclosure policy, the originator chooses the optimal security to issue given his type. His expected payoff in equilibrium is given by

$$U_H^{ih} \equiv (1-\delta)p(\mathcal{F}^{ih}) + \delta[\pi V_G + (1-\pi)(V_B + \theta_H X)] \tag{6}$$

where $\mathcal{F}^{ih}$ is given by Eq. 3 for $\hat{\lambda}_i = \lambda_i^{ih}$.

To conclude this subsection, we would like to emphasise the *ex ante* inefficiency with in-house servicing. The high-type securitiser's zero foreclosure policy reduces the expected value of the mortgage pool significantly. Anticipating this to happen in a bad state in equilibrium, investors would pay a much lower price for the MBS ex ante. In the end, the securitiser himself bears the cost of excessive forbearance and hence if possible, he would like to commit to foreclose more, which is an *ex post* suboptimal foreclosure policy. One of the main messages of this paper is that by hiring a third-party servicer, instead of servicing mortgages in-house, the securitiser can overcome this commitment problem and hence increase his ex ante expected payoff.

4.3 Securitisation with third-party servicing

We now turn to consider the case with third-party servicing. We first examine the equilibrium foreclosure decision in this case, then consider the design of the servicing contract offered by the second bank. This section offers insight into the role played by a third-party servicer in the securitisation process.

Suppose the originator of type i accepts the servicing contract (α, β, τ) and remains as a third-party servicing. At $t = 2$, the third-party servicer chooses a foreclosure policy to maximise his expected servicing fee

$$\max_{\lambda_i \in [0,1]} \quad \alpha[\beta\, \mathcal{L}(\lambda_i) + (1 - \lambda_i)\theta_i X] \tag{7}$$

The first order condition for the above programme is $\beta \frac{\partial \mathcal{L}(\lambda_i)}{\partial \lambda_i} = \theta_i X$. Denote the optimal choice of foreclosure policy by the third-party servicer $\lambda_i^s(\beta)$. There following lemma states an important property of the servicing contract.

Lemma 1. *In the interior region, $\lambda_i^s(\beta)$ is strictly increasing in β, and equal to λ_i^{FB} if and only if $\beta = 1$.*

Since β captures the relative payment to the servicer from foreclosure cash flows compared to recovery cash flows, Lemma 1 follows naturally.

Denote the originator's expected payoff given his private information θ and his choice of contract $w_i(\alpha, \beta, \tau)$, given by

$$w_i(\alpha, \beta, \tau) \equiv \tau + \delta\alpha[\beta\, \mathcal{L}(\lambda_i^s(\beta)) + (1 - \lambda_i^s(\beta))\theta_i X] - \kappa \tag{8}$$

We now consider the design of the servicing contract offered by the securitiser to the originator. The following lemma establishes the nature of the contracts offered in equilibrium.

Lemma 2. *In equilibrium, the securitiser either offers a menu of two distinct contracts* $\{(\alpha_i, \beta_i, \tau_i)\}_{i\in\{H,L\}}$ *such that both types of originators accept, or offers a menu of contracts such that both types of originators reject.*

Lemma 2 suggests that, for γ low, a pooling contract that is identical and accepted by both types cannot be part of the equilibrium. In this case, the securitiser benefits from becoming informed by offering a screening menu of contracts to solicit information from the originator. Moreover, the screening contract cannot be such that only one type accepts. Intuitively, given that the securitiser is informed, she best takes advantage of her information by securitising both types of the mortgage pool.

Given Lemma 2, since the securitiser is uninformed about the quality of the mortgage pool θ at $t = 0$, she offers a menu of two contracts to screen the informed originator. The choice of contract then reveals the information to the securitiser, who then securitises the security facing asymmetric information between her and the outside investors. The servicing contracts that maximises the expected payoff to the securitiser is given by

$$\begin{aligned}
\max_{\{(\alpha_i,\beta_i,\tau_i)\}_{i\in\{H,L\}}} \quad & \gamma[U_H(\lambda_H^{tp}, \lambda_L^{tp}) - w_H(\alpha_H, \beta_H, \tau_H)] \\
& \qquad + (1-\gamma)[U_L(\lambda_L^{tp}) - w_L(\alpha_L, \beta_L, \tau_L)] \\
s.t. \quad (PC) \quad & w_i(\alpha_i, \beta_i, \tau_i) \geq U_i^{ih} \; \forall \, i \in \{H, L\} \\
(IC_H) \quad & w_H(\alpha_H, \beta_H, \tau_H) \geq w_H(\alpha_L, \beta_L, \tau_L) \\
(IC_L) \quad & w_L(\alpha_L, \beta_L, \tau_L) \geq w_L(\alpha_H, \beta_H, \tau_H) \\
& \lambda_i^{tp} = \lambda_i^s(\beta_i) \; \forall \, i \in \{H, L\} \\
& U_H(\lambda_H, \lambda_L) \equiv (1-\delta)p(\mathcal{F}^{tp}) \\
& \quad + \delta(\pi V_G + (1-\pi)[V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)\theta_H X]) \\
& \mathcal{F}^{tp} \text{ is given by Eq. 3 for } \hat{\lambda}_i = \lambda_i^{tp}
\end{aligned} \tag{9}$$

where (PC) is the participation constraint for an originator of type i to be willing to accept servicing contract i, and (IC_i) is the incentive compatibility constraint for an originator of type i to prefer servicing contract i to the other contract offered in the menu. The above programme restricts that the securitiser only makes offers that the originator of either type accepts through (PC). This is without loss of generality, since the the securitiser is indifferent between making an offer that will not be accepted, and not making an offer at all.[13]

The following proposition states the properties of the equilibrium foreclosure policy in the sub-game in which an offer is accepted and the securitiser securitises the mortgage pool while the originator remains a third-party servicer.

Denote $(\tilde{\lambda}_H, \tilde{\lambda}_L)$ the foreclosure policy that maximises the ex ante expected payoff, if the securitiser must securitise under asymmetric information, but can commit to a foreclosure policy ex post. This is given by

$$\begin{aligned}(\tilde{\lambda}_H, \tilde{\lambda}_L) = \arg \max_{(\lambda_H, \lambda_L)} \quad & \gamma\delta(\pi V_G + (1-\pi)[V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)\theta_H X]) \\ & +\gamma(1-\delta)p(\mathcal{F}) + (1-\gamma)U_L(\lambda_L) \\ s.t. \quad & \mathcal{F} \text{ is given by Eq. 3 with } \hat{\lambda}_i = \lambda_i \end{aligned} \tag{10}$$

Proposition 4. *In equilibrium, the securitiser makes an offer that is accepted by the originator if and only if* $\kappa \leq [\gamma U_H(\tilde{\lambda}_H, \tilde{\lambda}_L) + (1-\gamma)U_L(\tilde{\lambda}_L)] - [\gamma U_H^{ih} + (1-\gamma)U_L^{ih}]$. *The equilibrium foreclosure policy with third-party servicing coincides with the foreclosure policy with commitment* $(\lambda_H^{tp}, \lambda_L^{tp}) = (\tilde{\lambda}_H, \tilde{\lambda}_L)$, *where*

$$\lambda_H^{tp} < \lambda_H^{FB} < \lambda_L^{FB} \leq \lambda_L^{tp} \tag{11}$$

That is, in the bad state, there is insufficient foreclosure if the mortgage pool is of high quality, and (weakly) excessive foreclosure if the mortgage pool is of low quality. The last inequality is strict if and only if

$$\begin{aligned}\frac{\theta_H - \theta_L}{1-\theta_H}(1-\lambda_L^{tp})X \quad < \quad & [\mathcal{L}(\lambda_L^{tp}) - \mathcal{L}(\lambda_H^{tp})] \\ & -\frac{\pi}{1-\pi}\frac{1-\delta}{1-\theta_H}[\mathcal{L}(\lambda_H^{tp}) - \mathcal{L}(\lambda_L^{tp}) + (\lambda_L^{tp} - \lambda_H^{tp})X] \end{aligned} \tag{12}$$

Proposition 4 highlights a number of important results of this model. Firstly, the equilibrium foreclosure policy consists of a two-sided inefficiency. On the one hand, a high-type mortgage pool faces insufficient foreclosure. On the other hand,

[13] Moreover, there is never an equilibrium in which the securitiser makes an offer that is only accepted by one type but not the other. If the asset transfer leads outside investors to believe that the mortgage pool is of good type, the other type would always have an incentive to mimic and also accept the offer.

a low-type mortgage pool faces excessive foreclosure if the condition given by Eq. 12 holds. This is more likely to be the case when $\frac{\theta_H - \theta_L}{1-\theta_H}$ is low and when π is low, so that the information asymmetric problem in the securitisation process is severe.

The two-sided distortion in the equilibrium foreclosure policy with third-party servicing is driven by the signalling concern of the issuer under asymmetric information. Given the equilibrium payoff to the low-type issuer, consider the payoff if she mimics the high type and issues the security $\mathcal{F}$. This mimicking payoff is comprised of two parts – the cash proceeds she gets from the security issuance $p(\mathcal{F})$, and the value of the retained cash flow. The optimal foreclosure policy in equilibrium deviates from the first-best (also ex post efficient) benchmark in order to reduce the mimicking payoff, thereby relaxing the incentive compatibility constraint and reducing the retention cost of signalling in equilibrium.

This is achieved precisely through the two-sided distortion of the foreclosure policy. Recall two important features of the model. First, the optimal security issued by the good type is a debt like security in the bad state, leaving the issuer with a levered equity claim. Second, an increase in foreclosure of delinquent loans decreases the riskiness of the cash flows of the mortgage pool of a given type. The result then follows. One the one hand, the foreclosure policy of a high type securitiser is lower than first best so as to increase the riskiness of her cash flows. By Jensen's inequality, this then reduces the value of the issued debt-like, concave security and the incentive for a bad type to mimic. On the other hand, the foreclosure policy of a low-type securitiser is higher than first best so as to decrease the riskiness of her cash flows. This lowers the value of her retained equity should she mimics the high type.

Notwithstanding the ex post inefficient foreclosure policy, the equilibrium with third-party servicing implements the optimal ex ante foreclosure policy when the securitiser can commit to such foreclosure. Compared to the previous section of securitisation with in-house servicing, securitisation is more efficient under third-party servicing, as stated in the following corollary.

Corollary 1. *The expected value of the mortgage pool in equilibrium is strictly higher in the case with third-party servicer than in the case with in-house servicer.*

That is,

$$\gamma U_H(\lambda_H^{tp}, \lambda_L^{tp}) + (1-\gamma)U_L(\lambda_L^{tp}) > \gamma U_H^{ih} + (1-\gamma)U_L^{ih} \tag{13}$$

This result highlights the role played by the third-party servicer in the securitisation process. With in-house servicing, the foreclosure policy is determined ex post by the securitiser given his private information and given that he retains a residual levered equity claim from the mortgage pool. With third-party servicing, the separation of cash flow rights and servicing rights allows the securitiser to effectively commit to a set of ex post inefficient foreclosure policy, that maximises the ex ante expected value of the mortgage pool.

Naturally, the securitiser makes an offer to securitise with the originator as third-party servicer in equilibrium as long as the cost for the originator to act as a third-party servicer κ does not outweigh the benefit of having effective commitment power over the foreclosure policy through contracting with a third-party servicer.

Lastly, the equilibrium servicing contracts offered to the originator appear to contain biased incentives.

Corollary 2. *The servicing contracts offered to the originator in equilibrium are such that* $\beta_H^{tp} < 1 \leq \beta_L^{tp}$*, where the last inequality is strict if and only if the condition given by Eq. 12 holds.*

Given the previous discussion, the securitiser is able to effectively commit to a set of ex ante foreclosure policy through contracting with a third-party servicer. Therefore the contracts to the servicer contains endogenously biased incentives, in order to implement the desired foreclosure policy. In particular, for a mortgage pool of low quality, the servicer's contract is biased towards excessive foreclosures.

5 Empirical implications

This section summarises the empirical implications of our model related to foreclosure policy and characteristics of mortgage servicers' compensation contracts. We make the following distributional predictions (1–2) regarding the foreclosure policy unconditional on the unobservable quality of the mortgage pool, and directional predictions (3–5) regarding the foreclosure policy and the servicers' contracts conditional on the unobservable quality of the mortgage pool (ex post observable given the security issued).

1. *Securitised mortgages serviced by third-party servicers are foreclosed more on average than comparable mortgages with in-house servicers.* Our model shows that in-house servicers face a time-inconsistency problem and cannot commit to the ex ante optimal foreclosure policy. An in-house servicer chooses little foreclosure when he is of the high type because he holds a levered equity claim, but chooses the ex post efficient level of foreclosure when he is of the low type. A third-party servicer, on the other hand, implements the optimal foreclosure policy which is insufficient when he is of the high type and excessive when he is of the low type (Proposition 3). In either case, the third-party servicer forecloses more than an in-house servicer of the same type. Therefore we expect to observe higher foreclosure rates by third-party servicers on average.

2. *Securitised mortgages on average face higher uncertainty regarding foreclosure than comparable bank-held loans.*

3. *Low (high) quality securitised mortgage pools have a higher (lower) foreclosure rate than comparable bank-held loans.* This and the previous prediction follows from the main result of our model, which shows that the asymmetric information friction in the process of mortgage securitisation will distort foreclosures of delinquent mortgage towards the extremes in a bad state (Proposition 4). That is, good quality securitised loans are foreclosed less than first best, whereas bad quality securitised loans are foreclosed more than first best. The empirical findings of Piskorski et al. (2010) and Agarwal et al. (2011a) can be suggestive that the overall proportion of low quality mortgage pools are sufficient high, so that the average unconditional foreclosure rate for securitised loans is high than for bank-held loans.

4. *The foreclosure rate of delinquent mortgages in a low (high) quality securitised pool is higher (lower) than the ex post efficient level.* Specifically we show that when the mortgage pool is of low quality, the proceeds from foreclosing the marginal mortgage are *lower* than its expected recovery value, i.e. its foreclosure entails negative NPV. This is in line with the finding of Levitin (2009).

5. *The third-party servicer's contract with a low (high) quality mortgage pool is biased towards (against) foreclosure.* We show that the securitiser offers an optimal incentive contract to a third-party servicer to implement the ex ante optimal foreclosure policy (Corollary 2). This is in line with the anecdotal evidence of Goodman (2009).

6 Conclusion

The recent subprime mortgage crisis has raised concerns regarding the economic and social consequences of mortgage backed securitisation. In particular, the United States experienced a "foreclosure crisis" subsequent to the crisis in 2008 that received much public attention. Recent studies and reports have suggested that securitisation and the biased incentives of mortgage services could have contributed to the foreclosure wave. This paper formally studies the relationship between the foreclosure decision of delinquent loans and the securitisation of mortgages, and examines the role of mortgage servicers in this process.

We investigate the optimal servicing arrangement and foreclosure decision in a model of mortgage-backed securitisation under asymmetric information. A securitiser with a pool of mortgages has private information regarding the recovery rate of the mortgages that ex post become delinquent. The securitiser initially designs and sells a mortgage-backed security, and makes the decision whether to foreclose or modify a mortgage when it becomes delinquent ex post.

Relative to the case with full information, we show that the optimal foreclosure policy under asymmetric information involves excessive foreclosure if the mortgage pool is of low quality, and insufficient foreclosure if the mortgage pool is of high quality. This is because the signalling concern at the securitisation stage prompts the securitiser to take procedures at the foreclosure stage to reduce the information sensitivity of the mortgage pool cash flows. Thus we provide a theory that predicts securitisation will distort forelcosure policy due to information friction.

Moreover, we address the role played by third-party servicers in the mortgage backed securitisation industry. By contracting with a third-party servicer, the securitiser is able to effectively commit to an ex ante optimal foreclosure policy, which reduces the signalling cost of securitisation in equilibrium.

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Appendices

A Proofs

A.1 Proof of Proposition 1

The first-best foreclosure level λ_i^{FB} for type i maximises the expected payoff of the mortgage pool $V_B + \mathcal{L}(\lambda_i) + (1-\lambda_i)\theta_i X$. Thus the first order condition is $\frac{\partial \mathcal{L}(\lambda_i^{FB})}{\partial \lambda_i} = \theta_i X$ for $i \in \{H, L\}$. Using the functional form of $\mathcal{L}(\lambda) = aX\ln(1+\frac{\lambda}{a})$, the results follow immediately.

A.2 Proof of Proposition 2

Before proceeding to the proof, let's recall the possible realisation of cash flows of the mortgage pool and the security payoff issued by the high type.

Table 2: Payoffs of the security issued by the high type

Realisation of cash flow	Security payoff $\mathcal{F}$
$c_1 \equiv V_G$	f_1
$c_2 \equiv V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)X$	f_2
$c_3 \equiv V_B + \mathcal{L}(\lambda_L) + (1-\lambda_L)X$	f_3
$c_4 \equiv V_B + \mathcal{L}(\lambda_L)$	f_4
$c_5 \equiv V_B + \mathcal{L}(\lambda_H)$	f_5

We focus on the case with the following ranking of cash flow: $c_1 > c_2 > c_3 > c_4 > c_5$, which will be the case if the equilibrium foreclosure rate satisfies $\lambda_L > \lambda_H$.

In a separating equilibrium, the optimal strategy for the low type is to issue all of the equity to outside investors in order to minimise the retention cost. And the optimal (monotone) security for the high type has to satisfy incentive compatibility (IC) constraint to prevent the low type from mimicking, the set of limited liability constraints and the monotonicity constraints for both securities hold by outside investors (MNO) and retained by insiders (MNI) securities. Combining with limited liability constraints, the constraints can be re-written as:

$$(IC) \qquad U_L \geq \pi f_1 + (1-\pi)[\theta_H f_2 + (1-\theta_H) f_5] \\ + \delta\{\pi(c_1 - f_1) + (1-\pi)[\theta_L(c_3 - f_3) + (1-\theta_L)(c_4 - f_4)]\} \tag{14}$$

$$(MNO) \quad f_1 \geq f_2 \geq f_3 \geq f_4 \geq f_5 \geq 0 \tag{15}$$

$$(MNI) \quad c_1 - f_1 \geq c_2 - f_2 \geq c_3 - f_3 \geq c_4 - f_4 \geq c_5 - f_5 \geq 0 \tag{16}$$

And the objective is to design an security $\mathcal{F} = \{f_1, f_2, f_3, f_4, f_5\}$ in order to maximise the high type's securities selling price

$$p(\mathcal{F}) = \pi f_1 + (1-\pi)[\theta_H f_2 + (1-\theta_H) f_5] \tag{17}$$

The proof is constructed by establishing several claims in succession. Let us call a security $\mathcal{F}$ *permissible* if it satisfies (IC), (MNO), and (MNI). An optimal security is a permissible security that maximises the payoff $p(\mathcal{F})$.

Claim 1: For any optimal security $\mathcal{F}^* = \{f_1^*, f_2^*, f_3^*, f_4^*, f_5^*\}$, $f_1^* < c_1$.
If $f_1^* = c_1$, by (MCI), $f_j^* = c_j$ for $j = \{2, 3, 4, 5\}$. This security (full equity) violates (IC).

Claim 2: For any optimal security $\mathcal{F}^*$, the (IC) must bind.
Suppose instead the (IC) is slack for some optimal security $\mathcal{F}^* = \{f_1^*, f_2^*, f_3^*, f_4^*, f_5^*\}$. By Claim 1, $f_1^* < c_1$. Unless $c_1 - f_1^* = c_2 - f_2^*$, there exists another permissible security $\hat{\mathcal{F}} = \{\hat{f}_1, f_2^*, f_3^*, f_4^*, f_5^*\}$ with $\hat{f}_1 > f_1^*$ that satisfies (IC). As $p(\mathcal{F})$ strictly increases with f_1, $p(\hat{\mathcal{F}}) > p(\mathcal{F}^*)$, contradicting the assumption that $\mathcal{F}^*$ is optimal.

If $f_1^* < c_1$ and $c_1 - f_1^* = c_2 - f_2^*$, one can increase the objective function $p(\mathcal{F}^*)$ by increasing both f_1^* and f_2^* by some $\epsilon > 0$ without violating (IC), unless $f_2^* = c_2$ or $c_2 - f_2^* = c_3 - f_3^*$. Note that $f_2^* = c_2$ is not possible as it implies $f_1^* = c_1$ violating Claim 1.

Suppose now $f_1^* < c_1$ and $c_1 - f_1^* = c_2 - f_2^* = c_3 - f_3^*$, similarly one can increase all f_1^*, f_2^*, f_3^* without violating (IC) to strictly increase $p(\mathcal{F}^*)$, unless $c_3 - f_3^* = c_4 - f_4^*$.

By similar argument, we reach the last possible case with $f_1^* < c_1$ and $c_1 - f_1^* = c_2 - f_2^* = c_3 - f_3^* = c_4 - f_4^* = c_5 - f_5^*$. One can increase all f_i^* by a small amount without violating (IC) unless $f_5^* = c_5$ which also leads to a contradiction that $f_1^* = c_1$. Since we have shown any optimal security with a slacking (IC) can be improved upon, all optimal securities must have the (IC) binding.

Claim 3: For any optimal security $\mathcal{F}^*$, either $f_{j-1}^* = f_j^*$ or $c_j - f_j^* = c_{j+1} - f_{j+1}^*$ (or both) for $j = \{3, 4\}$.

Let's start with the case with $j = 3$. The proof proceeds by contradiction. Suppose there is an optimal security $\mathcal{F}^* = \{f_1^*, f_2^*, f_3^*, f_4^*, f_5^*\}$ with $f_2^* > f_3^*$ and $c_3 - f_3^* > c_4 - f_4^*$. Since the (IC) is relaxed by increasing f_3, one can construct another permissible security $\hat{\mathcal{F}} = \{f_1^*, f_2^*, \hat{f}_3, f_4^*, f_5^*\}$ with some $\hat{f}_3 > f_3^*$. Notice that this security $\hat{\mathcal{F}}$ has the same price as $\mathcal{F}^*$, i.e. $p(\hat{\mathcal{F}}) = p(\mathcal{F}^*)$, as $p(\mathcal{F})$ does not depend on f_3. However, by Claim 2 and the fact that the (IC) is slack under security $\hat{\mathcal{F}}$, $\hat{\mathcal{F}}$ is not an optimal security. In other words, there exists another permissible security $\hat{\hat{\mathcal{F}}}$ such that $p(\hat{\hat{\mathcal{F}}}) > p(\hat{\mathcal{F}}) = p(\mathcal{F}^*)$. As a result, the assumption that $\mathcal{F}^*$ is optimal is contradicted.

The proof is identical for the case with $j = 4$.

Claim 4: For any optimal securities $\mathcal{F}^*$, $f_3^* > f_4^*$.

Suppose that $f_3^* = f_4^*$, which implies $c_3 - f_3^* > c_4 - f_4^*$. By Claim 3, $f_2^* = f_3^* = f_4^*$. But (IC) is slack under this $\mathcal{F}^*$, violating its optimality assumption by Claim 2. To see this, note that the (IC) can be written as:

$$(1-\delta)U_L \geq \pi(1-\delta)f_1 + (1-\pi)[\theta_H f_2 + (1-\theta_H)f_5] - \delta(1-\pi)[\theta_L f_3 + (1-\theta_L)f_4] \tag{18}$$

For security $\mathcal{F}^*$ with $f_2^* = f_3^* = f_4^*$, the right-hand side of the IC in Eq. (18) is strictly less than its left-hand side:

$$\begin{aligned} &\pi(1-\delta)f_1^* + [(1-\pi)\theta_H - \delta(1-\pi)]f_4^* + (1-\pi)(1-\delta_H)f_5^* \\ \leq &\pi(1-\delta)f_1^* + (1-\pi)(1-\delta)f_4^* \\ < &(1-\delta)\{\pi c_1 + (1-\pi)[\theta_L c_3 + (1-\delta_L)c_4]\} = (1-\delta)U_L \end{aligned}$$

The first weak inequality follows from $f_4^* \geq f_5^*$. The second strict inequality follows from $f_1^* < c_1$ (Claim 1), $f_4^* \geq f_3^*$, $c_3^* \geq f_3^*$, and $c_4^* \geq f_4^*$.

Claim 5: For an optimal security $\mathcal{F}^*$, $f_4^* = c_4$ and $f_5^* = c_5$.

To prove Claim 5, we will show that for any optimal security $\mathcal{F}^*$ with $f_4^* < c_4$, there exists another permissible, payoff-equivalent security with which the (IC) is slack. By Claim 2, therefore, $\mathcal{F}^*$ cannot be an optimal security.

By Claim 3 and 4, we know $f_3^* > f_4^*$ and $c_4 - f_4^* = c_5 - f_5^*$. Suppose that $f_4^* < c_4$, implying $c_4 - f_4^* = c_5 - f_5^* > 0$, we will show that one can simultaneously (i) increase both f_4^* and f_5^* by a small positive ϵ and (ii) decrease some $\{f_i^*\}$ to keep the payoff unchanged while relaxing the (IC). Consider the follow two (exhaustive) cases for any optimal security $\mathcal{F}^*$:

(I). $c_1 - f_1^* > c_2 - f_2^*$ and $f_2^* \geq f_3^*$:

Pick an arbitrarily small, positive ϵ. Construct a new security $\hat{\mathcal{F}}$ from $\mathcal{F}^*$ by increasing f_4^* and f_5^* by $\frac{1}{1-\theta_H}\epsilon$ and decreasing f_2^* and f_3^* by $\frac{1}{\theta_H}\epsilon$. By construction, $p(\hat{\mathcal{F}}) = p(\mathcal{F}^*)$ whereas the (IC) is slack under $\hat{\mathcal{F}}$. To see this, the RHS of the (IC) shown in eq. (18) is reduced by $\delta(1-\pi)\frac{\theta_H-\theta_L}{\theta_H(1-\theta_H)} > 0$. Therefore, by Claim 2, $\hat{\mathcal{F}}$ is not optimal and there exists another permissible $\hat{\hat{\mathcal{F}}}$ such that $p(\hat{\hat{\mathcal{F}}}) > p(\hat{\mathcal{F}}) = p(\mathcal{F}^*)$, contradicted the optimality assumption of $\mathcal{F}^*$.

(II). $c_1 - f_1^* = c_2 - f_2^*$ and $f_2^* \geq f_3^*$:

Pick an arbitrarily small, positive ϵ. Construct a new security $\hat{\mathcal{F}}$ from $\mathcal{F}^*$ by increasing f_4^* and f_5^* by $\frac{1}{(1-\pi)(1-\theta_H)}\epsilon$ and decreasing f_1^* by $\frac{1}{\pi}\epsilon$ (Note that $c_1 - f_1^* = c_2 - f_2^*$ implies $f_1^* > f_2^*$). It is immediate to check that $p(\hat{\mathcal{F}}) = p(\mathcal{F}^*)$ and the (IC) is relaxed by $\delta(\frac{\theta_H-\theta_L}{1-\theta_H})\epsilon > 0$. By similar reasons stated in case (I), $\mathcal{F}^*$ is not optimal.

As all the possible cases of a potential optimal security with $f_4^* < c_4$ lead to contradictions, we have shown that (with limited liability constraint) for any optimal security, $f_4^* = c_4$.

By (MCI), $0 = c_4 - f_4^* \geq c_5 - f_5^*$, thus $f_5^* = c_5$.

Claim 6: For any optimal security $\mathcal{F}^*$, $c_1 - f_1^* = c_2 - f_2^*$.

Suppose contrary that $c_1 - f_1^* > c_2 - f_2^*$, pick an arbitrarily small, positive ϵ and construct a new security $\hat{\mathcal{F}}$ from $\mathcal{F}^*$ by increasing f_1^* by $\frac{1}{\pi}\epsilon$ and decreasing f_2^* and

f_3^* by $\frac{1}{(1-\pi)\theta_H}\epsilon$. It is immediate to check that $p(\hat{\mathcal{F}}) = p(\mathcal{F}^*)$ and the (IC) is relaxed by $\delta(1 - \frac{\theta_L}{\theta_H})\epsilon > 0$.

To sum up, Claim 1 to 6 establish that the optimal security $\mathcal{F}^*$ will be one of the following two cases:

1. $c_1 > f_1^* = (c_1 - c_2) + f_2^* > f_2^* > f_3^* = c_3 > f_4^* = c_4 > f_5^* = c_5$
2. $c_1 > f_1^* = (c_1 - c_2) + f_2^* > f_2^* = f_3^* > f_4^* = c_4 > f_5^* = c_5$

The only differences between the two cases is whether $f_2^* > f_3^*$ or $f_2^* = f_3^*$.[14] In both cases, there remains only one free parameter f_2^* in the optimal security. And since we know the (IC) binds for any optimal security, f_2^* will be pinned down by the (IC).

For case 1, substitute $f_1^* = c_1 - c_2 + f_2^*$,$f_3^* = c_3$,$f_4^* = c_4$, $f_5^* = c_5$ into the (IC). Then the f_2^* satisfies (IC)

$$U_L = \pi(c_1 - c_2 + f_2^*) + (1-\pi)[\theta_H f_2^* + (1-\theta_H)c_5] + \delta\pi(c_1 - c_1 + c_2 - f_2^*)$$

Hence

$$f_2^* = \frac{U_L - \pi c_1 + \pi(1-\delta)c_2 - (1-\pi)(1-\theta_H)c_5}{\pi(1-\delta) + (1-\pi)\theta_H} \tag{19}$$

$$= \frac{\pi(1-\delta)c_2 + (1-\pi)[\theta_L c_3 + (1-\theta_L)c_4 - (1-\theta_H)c_5]}{\pi(1-\delta) + (1-\pi)\theta_H} \tag{20}$$

Similarly, for case 2, substitute $f_1^* = c_1 - c_2 + f_2^*$,$f_3^* = f_2^*$,$f_4^* = c_4$, $f_5^* = c_5$ into the (IC). Then

$$f_2^* = \frac{U_L - \pi c_1 + \pi(1-\delta)c_2 - \delta(1-\pi)\theta_L c_3 - (1-\pi)(1-\theta_H)c_5}{\pi(1-\delta) + (1-\pi)(\theta_H - \delta\theta_L)} \tag{21}$$

$$= \frac{\pi(1-\delta)c_2 + (1-\pi)[\theta_L(1-\delta)c_3 + (1-\theta_L)c_4 - (1-\theta_H)c_5]}{\pi(1-\delta) + (1-\pi)(\theta_H - \delta\theta_L)} \tag{22}$$

Finally, we need to check whether $f_2^* > f_3^* = c_3$ in case (1) and $f_2^* = f_3^* \leq c_3$ in

[14] Note that $f_2^* > f_3^*$ implies $f_3^* = c_3$ because of Claim 3 and 5.

case (2). Define $G(\theta_H, \theta_L; \pi; \delta)$ as

$$G(\theta_H, \theta_L; \pi; \delta) \equiv \theta_H(c_3 - c_5) - \theta_L(c_3 - c_4) - \frac{\pi}{1-\pi}(1-\delta)(c_2 - c_3) + (c_4 - c_5) \tag{23}$$

For $G(\theta_H, \theta_L; \pi; \delta) > 0$, we have the $f_2^* > f_3^* = c_3$ as in case (1). Similarly for $G(\theta_H, \theta_L; \pi; \delta) \leq 0$, the optimal security is described as in case (2) where $f_2^* = f_3^* \leq c_3$.

A.3 Proof of Proposition 3

Omitted.

A.4 Proof of Lemma 1

This result follows immediate by implicitly differentiating the first order condition $\beta \frac{\partial \mathcal{L}(\lambda_i)}{\partial \lambda_i} = \theta_i X$ with regard to β.

A.5 Proof of Lemma 2

We prove this lemma by first ruling out a pooling contract in equilibrium that is identical and accepted by both types, and then rule out screening contracts such that only one type accepts in equilibrium.

No pooling contract in equilibrium.

Conjecture a pooling contract in equilibrium (α, β, τ). Since both types accept this contract in equilibrium, the contract satisfies the participation constraint (PC) for both types $w_i(\alpha, \beta, \tau) \geq U_i^{ih}$ for $i \in \{H, L\}$. Moreover, in this case the securitiser is uninformed in equilibrium. She therefore securitises the mortgage pool to outside investor under symmetric information and at fair price. As a result, she optimally issues a pass through equity security, which is priced at $p(\beta) = \gamma(\pi V_G + (1-\pi)[V_B + \mathcal{L}(\lambda^s(\beta)) + (1-\lambda^s(\beta))\theta_H X]) + (1-\gamma)U_L(\lambda^s(\beta))$. The securitiser's expected payoff in equilibrium is given by

$$\gamma[p(\beta) - w_H(\alpha, \beta, \tau)] + (1-\gamma)[p(\beta) - w_L(\alpha, \beta, \tau)]$$

We now prove this claim by establish two properties of a pooling contract equilibrium, and then show that there always exist a profitable deviation.

Firstly, $\beta = 1$ in any equilibrium with a pooling contract. We show that otherwise there exists a profitable deviation. Suppose $\beta \neq 1$. Then a deviation to β' closer to 1 increases $p(\cdot)$. Moreover, there exists α' and τ' such that $w_i(\alpha, \beta, \tau) = w_i(\alpha', \beta', \tau')$ for $i \in \{H, L\}$.

Secondly, (PC) binds in any equilibrium with a pooling contract. Again, suppose that $w_i(\alpha, 1, \tau) > U_i^{ih}$. Then there exists α' and τ' such that $w_i(\alpha', 1, \tau') < w_i(\alpha', 1, \tau')$ and $w_j(\alpha', 1, \tau') = w_j(\alpha, 1, \tau)$, $j \neq i$.

The previous two properties imply that the securitiser's expected payoff in an equilibrium with a pooling contract is equal to

$$\gamma[p(1) - U_H^{ih}] + (1-\gamma)[p(1) - U_L^{ih}]$$

Notice that since $p(1) = \gamma U_H^{FB} + (1-\gamma) U_L^{FB}$, $U_H^{FB} > U_H^{ih} > U_L^{ih} = U_L^{FB}$. If $\gamma < \frac{U_H^{ih} - U_L^{ih}}{U_H^{FB} - U_L^{FB}}$, $p(1) < U_H^{ih}$. That is, the securitiser makes a loss if the mortgage pool is of low quality.

We then construct a deviation $(\alpha', 1, \tau')$ such that $w_H(\alpha', 1, \tau') < U_H^{ih}$ and $w_i(\alpha', 1, \tau') = U_L^{ih}$, so that the contract is only accepted by a low type originator. The securitiser thus strictly profits from such derivation, given the outside investor's belief that the security issued by the securitiser is of the average quality and thus warrants a price $p(1)$.

No screening contract that is only accepted by the high type in equilibrium. Conjecture a screening contract in equilibrium $\{(\alpha_i, \beta_i, \tau_i)\}_{i \in \{H,L\}}$ such that $w_H(\alpha_H, \beta_H, \tau_H) \geq U_H^{ih}$ and $w_L(\alpha_L, \beta_L, \tau_L) < U_L^{ih}$. Subsequently, she securitises the high type mortgage pool with third-party servicing, whilst the originator securitises the low type mortgage pool with in-house servicing. Since it is a fully separating equilibrium, each securitiser obtains the fair value on the pass through securities issued. By similar reasoning as before, the equilibrium contract must have $\beta_H = 1$ and (PC) binding for the high type, i.e. $w_H(\alpha_H, \beta_H, \tau_H) = U_H^{ih}$. The equilibrium payoff to the securitiser is thus given by $\gamma[p(1) - U_H^{ih}]$.

We now construct a deviation $(\alpha_L', 1, \tau_L')$ such that $w_H(\alpha_L', 1, \tau_L') = U_L^{ih}$, so that the contract is also accepted by a low type originator. Given that the outside investors hold the belief that the securitiser has a high quality mortgage pool, the securitiser strictly benefits from such a deviation.

No screening contract that is only accepted by the low type in equilibrium. Suppose there exists an equilibrium with a screening contract $\{(\alpha_i, \beta_i, \tau_i)\}_{i\in\{H,L\}}$ that is only accepted by the low type in equilibrium. Subsequently, she securitises the low type mortgage pool with third-party servicing, whilst the originator securitises the high type mortgage pool with in-house servicing. Since it is a fully separating equilibrium, each securitiser obtains the fair value on the pass through securities issued.

However, this implies that if a low type originator deviates and rejects the contract, he can also securitise a pass through security and obtain a high price equal to U_H^{FB}, given that the outside investors' belief that the originator securitises a high quality mortgage pool in equilibrium. This implies that the equilibrium contract satisfies $w_H(\alpha_H, \beta_H, \tau_H) < U_H^{FB}$ and $w_L(\alpha_L, \beta_L, \tau_L) \geq U_H^{FB}$, and the expected payoff to the securitiser is $(1-\gamma)[U_L^{FB} - U_H^{FB}] < 0$. This is a contradiction.

A.6 Proof of Proposition 4

We prove this proposition by first conjecturing that the equilibrium foreclosure policy is given by $(\tilde{\lambda}_H, \tilde{\lambda}_L)$, where $\tilde{\lambda}_H < \tilde{\lambda}_L$. We then show that there exists a menu of servicer contracts that implements such foreclosure policy and satisfies (IC_i) and binds (PC), given in the optimisation programme Eq. 9. It then follows that such contracts indeed maximises the expected payoff to the securitiser as specified by Eq. 9. We finally characterise the properties of the equilibrium foreclosure policy and confirm that indeed $\tilde{\lambda}_H < \tilde{\lambda}_L$.

In order to implement an equilibrium foreclosure policy equal to $(\tilde{\lambda}_H, \tilde{\lambda}_L)$, the equilibrium servicer contracts must have unique β_i^{tp} such that $\beta_i^{tp}\frac{\partial \mathcal{L}(\lambda_i^{tp})}{\partial \lambda_i} = \theta_i X$. The uniqueness follows from Lemma 1.

We then construct a menu of servicer contracts. Suppose that the flat transfer τ_i are such that (PC) binds. That is,

$$\tau_i^{tp} = U_H^{ih} + \kappa - \delta\alpha_i^{tp} K(\theta_i, \beta_i^{tp})$$

where $K(\theta_i, \beta) \equiv \beta\, \mathcal{L}(\lambda^s(\beta)) + (1 - \lambda^s(\beta))\theta_i X$. This implies that

$$\tau_H^{tp} - \tau_L^{tp} = (U_H^{ih} - U_L^{ih}) - \delta[\alpha_H K(\theta_H, \beta_H^{tp}) - \alpha_L K(\theta_L, \beta_H^{tp}] \tag{24}$$

Rearranging (IC_i) yields the following

$$\alpha_L K(\theta_L, \theta_L^{tp}) - \alpha_H K(\theta_L, \theta_H^{tp}) \geq \tau_H^{tp} - \tau_L^{tp} \geq \alpha_L K(\theta_H, \beta_L^{tp}) - \alpha_H K(\theta_H, \beta_H^{tp}) \tag{25}$$

Substituting Eq. 24 into 25 and rearranging produces

$$\alpha_L[K(\theta_H, \beta_L^{tp}) - K(\theta_L, \beta_L^{tp})] < \frac{U_H^{ih} - U_L^{ih}}{\delta} < \alpha_H[K(\theta_H, \beta_H^{tp}) - K(\theta_L, \beta_H^{tp})] \tag{26}$$

By the Envelope Theorem, we have $\frac{\partial K(\theta_i, \beta)}{\partial \beta} > 0$ and $\frac{\partial^2 K(\theta_i, \beta)}{\partial \beta \partial \theta_i} < 0$. Therefore we have $0 < K(\theta_H, \beta_L^{tp}) - K(\theta_L, \beta_L^{tp}) < K(\theta_H, \beta_H^{tp}) - K(\theta_L, \beta_H^{tp})$. Therefore there exist α_H^{tp} and α_L^{tp} such that the equilibrium contracts satisfy (IC_i), binds (PC), and implements the foreclosure policy $\lambda_i^{tp} = \tilde{\lambda}_i$.

We next characterise the equilibrium foreclosure policy by examining the solution to the optimisation programme given by Eq. 10. There are two cases given by Appendix A.2, depending on the specific feature of the security issued in equilibrium.

Consider first the case (1). Substituting in the optimal security characterised in Appendix A.2, the optimisation programme 10 can be written as

$$\begin{aligned}
\max_{\lambda_H, \lambda_L} \quad & \gamma\delta\left(\pi V_G + (1-\pi)[V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)\theta_H X]\right) \\
& + \gamma(1-\delta)[\pi + (1-\pi)\theta_H] f_2(\lambda_H, \lambda_L) \\
& + \gamma(1-\delta)(1-\pi)(1-\theta_H)[V_B + \mathcal{L}(\lambda_H)] \\
& + (1-\gamma)U_L(\lambda_L) \\
\text{where} \quad & f_2(\lambda_H, \lambda_L) = \frac{1}{\pi(1-\delta) + (1-\pi)\theta_H}\left(\pi(1-\delta)[V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)X]\right. \\
& \left. + (1-\pi)[V_B + \mathcal{L}(\lambda_L) + (1-\lambda_L)\theta_L X - (1-\theta_H)(V_B + \mathcal{L}(\lambda_H))]\right)
\end{aligned}$$

The solution to the above programme is given by the following first order conditions

$$
\begin{aligned}
(FOC_H) \qquad & \delta(1-\pi)(\frac{\partial \mathcal{L}(\lambda_H)}{\partial \lambda} - \theta_H X) + (1-\delta)[\pi + (1-\pi)\theta_H]\frac{\partial f_2(\lambda_H, \lambda_L)}{\partial \lambda_H} \\
& \qquad\qquad (1-\delta)(1-\pi)(1-\theta)\frac{\partial \mathcal{L}(\lambda_H)}{\partial \lambda} = 0 \\
(FOC_L) \qquad & \gamma(1-\delta)[\pi + (1-\pi)\theta_H]\frac{\partial f_2(\lambda_H, \lambda_L)}{\partial \lambda_L} \\
& \qquad\qquad +(1-\gamma)(\frac{\partial \mathcal{L}(\lambda_L)}{\partial \lambda} - \theta_L X) = 0 \qquad (27)
\end{aligned}
$$

Since the LHS of $(FOC_H) < 0$ at $\lambda_H = \lambda_H^{FC}$ and the LHS of $(FOC_L) = 0$ at $\lambda_L = \lambda_L^{FC}$, it follows that $\lambda_H^{tp} < \lambda_H^{FB}$ and $\lambda_L^{tp} = \lambda_L^{tp}$.

We then consider case (2). The optimisation programme is similar to above, but with

$$
\begin{aligned}
f_2(\lambda_H, \lambda_L) \quad = \quad & \frac{1}{\pi(1-\delta) + (1-\pi)(\theta_H - \delta\theta_L)}(\pi(1-\delta)[V_B + \mathcal{L}(\lambda_H) + (1-\lambda_H)X] \\
& +(1-\pi)\theta_L(1-\delta)[V_B + \mathcal{L}(\lambda_L) + (1-\lambda_L)X] \\
& +(1-\pi)[(1-\theta_L)[V_B + \mathcal{L}(\lambda_L)] - (1-\theta_H)[V_B + \mathcal{L}(\lambda_H)]]) \qquad (28)
\end{aligned}
$$

Similarly we have that the LHS of $(FOC_H) < 0$ at $\lambda_H = \lambda_H^{FC}$ and the LHS of $(FOC_L) > 0$ at $\lambda_L = \lambda_L^{FC}$. It then follows that $\lambda_H^{tp} < \lambda_H^{FB}$ and $\lambda_L^{tp} > \lambda_L^{tp}$ in this case.

A.7 Proof of Corollary 1

Notice that $(\lambda_H^{ih}, \lambda_L^{ih})$ and its corresponding equilibrium security also satisfies the constraint in the optimisation programme Eq. 10. The results of this corollary thus follows from the fact that $(\lambda_H^{tp}, \lambda_L^{tp})$ is the optimiser of said programme.

A.8 Proof of Corollary 2

The result follows immediately from Lemma 1 and Proposition 4.