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Early Commercial Mortgage Terminations and Real Estate Supply Constraints

In Fulfillment Of The Requirements For The Degree Of Doctor Of Philosophy

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Declaration:
I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Lok Man Michelle Tong

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Abstract
The early termination of commercial mortgages represents a financial risk for lenders. Default and prepayment risks are the two main options priced in the main literature, where competing risk models are adopted to analyze both risks simultaneously. In this research, we examines the impact of collateral underlying real estate supply constraints on early mortgage termination. To achieve this, we suggest three original ideas. First, as we need to estimate supply elasticities of office markets in the US, we develop a mismatch conceptual model estimating long run supply elasticity and computing the correlation between structural vacancy and supply constraints. The results imply that low controlling power of landlords reduces the flexibility in adjusting equilibrium vacancies to respond to market shocks. Second, we suggest adopting the installment option valuation model for pricing early mortgage termination options. Early mortgage termination (joint mortgage default and prepayment) is analogous to an American continuous installment option embedded with straddle or strangle like payoff as this can capture the decision path that keeps the option alive by making scheduled mortgage payments. Third, we suggest two pairs of early termination options: (1) mortgage default vs restructuring; and (2) full prepayment in cash vs defeasance in empirical analysis. The significant impacts of tightening property supply constraints on the likelihood of different types of early mortgage termination are proved. Overall, we expect that these three original ideas offer a helpful insight for mortgage originators and regulators as well as policymakers to manage related risk by including the geographical composition of collateral by supply constraints in risk models.

Contents

1 Introduction **7**

1.1 The Background of Commercial Mortgage Market in the US 7

1.2 Early Termination Options in Commercial Mortgages 9

1.3 Research Objectives 12

1.4 Thesis Structure 14

2 General Literature Review **15**

2.1 Overview 15

2.2 Key Research Topic: The Role of Securitization in Mortgage Markets 16

2.3 Contributions to Related Theories and Potential Extension 18

2.4 Critique of Empirical Strategies in Residential Mortgage Studies . 24

2.5 Critique of Empirical Studies of Commercial Mortgages 26

2.6 Expected Contributions of Our Research 31

3 Supply Elasticity and Search Equilibrium in Office Markets **34**

3.1 Abstract 34

3.2 Introduction 35

3.3 Literature Review 37

3.4 Conceptual Framework 43

3.4.1 Vacancy Type 44

3.4.2 Short Run and Long Run Supply Curve 45

3.4.3 Short- and Long-Run Equilibrium Rent 46

3.5 Empirical Strategy 48

3.5.1 Empirical Model 48

3.5.2 Dataset and Data Sources 53

3.5.3 Multicollinearity 59

3.5.4 Panel Unit Root and Cointegration Tests 61

3.6 Estimation Results 65

3.6.1 Long-Run Relationships 65

3.6.2 Short Run Dynamics 81
3.6.3 Robustness Tests 83
3.7 Final Discussion on Supply Elasticities 89
3.8 Conclusion 91
3.9 Appendix 93

4 Modelling Interactive Mortgage Termination Strategies 111
4.1 Abstract 111
4.2 Introduction 112
4.3 Literature Review 114
4.4 Theoretical Model 116
4.5 The Setup of Simulation 118
4.5.1 Risk free discounting 119
4.5.2 Property price process under risk neutral measure 119
4.5.3 Interest rate process under risk neutral measure 119
4.5.4 Deterministic mortgage terms 120
4.5.5 Valuing American continuous installment call options with early exercise and stopping boundaries 121
4.5.6 Valuing American continuous installment put options with early exercise and stopping boundaries 121
4.5.7 Valuing American continuous installment options with early exercise and stopping boundaries 122
4.5.8 Option valuation with least squares Monte Carlo method . 124
4.6 Parameterization 124
4.6.1 Interest Rate Process 124
4.6.2 Property Price Process 125
4.6.3 Mortgage Terms 128
4.6.4 Execution Costs 128
4.7 Simulation Results and Analysis 130
4.7.1 Comparison of Simple European Option Values with Analytic Solution 130
4.7.2 Valuing Mortgage Default Options When Prepayment Is Ignored 133
4.7.3 Valuing Prepayment Options When Mortgage Default Is Ignored 134
4.7.4 Valuing Early Termination Options: Joint Mortgage Default and Prepayment Options 134
4.7.5 One Dimensional vs Two Dimensional Model 135

4.7.6 Impact of Balloon Payments on Early Termination Options 138
4.7.7 Impact of Property Supply Constraints on Early Termination Options . . . 138
4.8 Conclusion . . . 141

5 Empirical Investigation of Borrowers' Strategic Choices 143
5.1 Abstract . . . 143
5.2 Introduction . . . 144
5.3 Literature Review . . . 145
5.4 Conceptual Framework . . . 148
5.5 Empirical Strategy . . . 150
5.5.1 Empirical Models . . . 150
5.5.2 Factors Driving the Exercise of Termination Options . . . 151
5.5.3 Data and Data Sources . . . 157
5.5.4 Data Issues . . . 162
5.6 Estimation Results and Discussion . . . 166
5.6.1 Early Mortgage Termination . . . 166
5.6.2 Partial Prepayment Behaviour . . . 174
5.6.3 Probabilities of Early Mortgage Termination and Partial Prepayment . . . 176
5.6.4 Robustness Check . . . 179
5.7 Conclusion . . . 184

6 Final Conclusion 186

Chapter 1

Introduction

1.1 The Background of Commercial Mortgage Market in the US

A large dispersion of mortgage market scales measured by the percentage of bank credits among G7 countries translates into a dissipative awareness of the potential instability of mortgage markets. The US catches the greatest global attention considering that its loan underwriting amount makes the US by far the largest lending market in the world. According to the Federal Reserve, mortgage lending accounts for over 30% of bank credits, with half of the collateralized real estate being commercial as represented in Figure 1.1.The great importance of the commercial mortgage market over the last decade is led by growing securitization of mortgages and a booming phase of the underlying real estate prices in the middle of 2000's. As underlying property prices have since turned and the commercial mortgage market ballooned, policymakers, financial institutions and investors of commercial mortgage backed securities (CMBS) monitor the health of the market particularly in the era post-subprime home mortgage crisis.
Commercial mortgages are designed with much more complicated terms than residential mortgages. The unique terms or covenants, in general, relate to the collateral (including its produced income) and hence reflect the importance of underlying buildings (not only measured by LTV) for commercial mortgage lenders. For example, the ability to repay a mortgage does not necessarily depend on the borrower's income, but on the amount of income the property generates above the mortgage service charge (i.e. features measured by the debt service coverage ratio, DSCR). Furthermore, cross collateralization represents an exclusive protection where the portfolio of collateral properties is pledged to guarantee a pool of mortgages. Therefore when any mortgage in the pool defaults, the lender facing

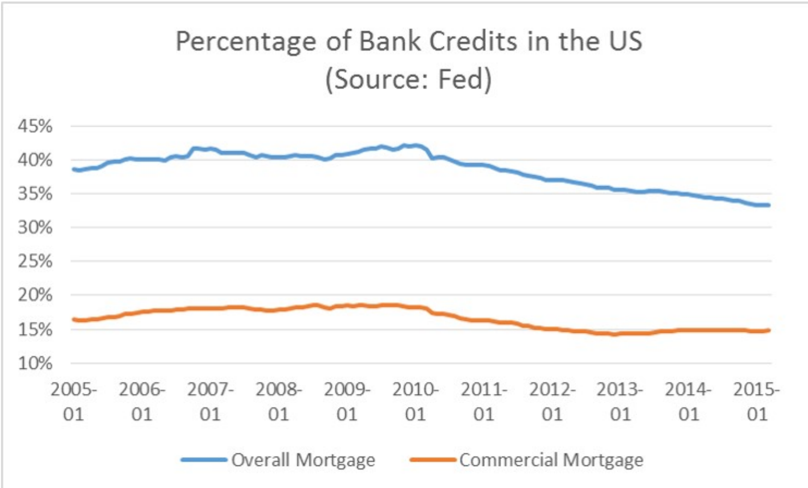


Figure 1.1: Commercial Mortgages: Percentage of Bank Credits (Source: Federal Reserve)

the occurrence from cross-default is allowed to recall the remaining mortgages within the pool. Another unique mortgage term in the commercial space refers to “defeasance”, which is the right offered to the borrower to swap the settlement method from “making payment as scheduled in cash” to “pledging Treasury securities” with similar cash flow patterns and redeeming the collateral property in return. These special designs of commercial mortgages related to the collateral are the primary motivation of our research.

Studies normally emphasize the aspects of corresponding property price growth and stability of rental income which is implicitly identified by tenant credibility, lease structure, physical quality of property, and quality of management team - Titman et al (2010 [163]). Apart from the specific collateral appraisal process, overall market trends such as vacancy rate, unemployment as a demand factor, and interest rate movements are also considered to examine mortgage risk. Despite some scholarly studies concentrate on the roles of originators or special servicers who manage delinquent loans and identify the best workout strategy to minimize default losses by negotiating with borrowers on payment streams - Chen et al (2013 [37], An et al (2013 [16]) -, originators or special servicers still rely on financial performance of the collateral and market conditions. However, the driving forces of collateral performances are yet to be fully explored, especially considering an important aspect related to the supply side price dynamics of underlying real estate markets.

In fact, property market dynamics are driven by interactive responses of demand and supply factors which may also affect the exercise of mortgage termination options. Citywide data availability on the demand side, a prominent demand shock during a financial crisis, and a calibrated identification of demand factors in general favour the concentration on the impact of demand shock in existing literature. In contrast, supply responses to these demand shocks are multidimensional, hard to identify except for newly built space and endogenous to the property market. These features somewhat hinder academic research to empirically study the links between property supply responses and mortgage risk.[1] To contribute to this under-explored area, this PhD research aims to quantify commercial property supply elasticities by adopting the calibrated searching theory based model and then examine how supply responses, in conjunction with demand shocks in underlying collateral real estate markets may trigger a change in the life cycle of commercial mortgages, which are modelled introducing a newly theoretical option pricing model which includes two types of early termination options - default and prepayment - and is empirically tested with two additional early termination options (i.e. restructuring and defeasance) using a database of US commercial mortgages.

1.2 Early Termination Options in Commercial Mortgages

The vast majority of existing literature merely investigates default and prepayment as early termination options. The subprime mortgage crisis and an enormous pool of home buyers which may bring more significant economic impact capture the focus on default and prepayment risk of home mortgages. Figure 1.2 shows the yield spread of commercial mortgage backed securities (CMBS) and home mortgages which should embed the related option value of prepayment and default. Since 2012 in the aftermath of the Global Financial Crisis (GFC), CMBS yield spreads have been greater than home mortgage spread. This suggests that the value of the CMBS underlying default and prepayment options tends to be higher than for home mortgages, requiring further investigation as set out among

[1] Tong(2014)[164]) investigated the impact of collateral underlying supply constrained market on commercial mortgage default, representing the only empirical research focused on the property supply response. However, the measurement of supply constraint in commercial property markets hinged on the estimates sourced from the research conducted by the industry practitioners without the adoption of proper econometric models and hence data estimates are somewhat questionable.

the goals of this thesis. Moreover defeasance, as an exit strategy available to commercial mortgages only, occurs quite often when interest rates hover at low levels. Notwithstanding rare empirical studies on defeasance, its great importance (considering lock-out cash prepayment clauses sometimes included in commercial mortgage contracts) suggests further exploration is needed. We strictly define early termination as a breach of "original mortgage contracts" with respect to the scheduled payments. Despite mortgage restructuring is normally separately studied in the existing literature of early termination options, we combine all available options to jointly investigate the borrower's decision in framework of competing options which result in a change of cash flow pattern.

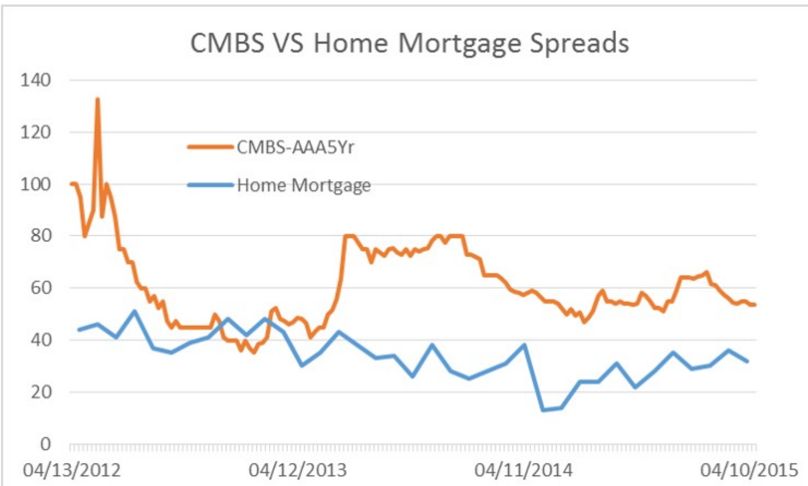


Figure 1.2: Comparison of Yield Spread: CMBS vs Home Mortgages (Sources: CRE News and the Mortgage Bankers Association)

At the beginning of this research, we list four types of early termination options, where default is paired with mortgage restructuring, and full prepayment in cash competes with defeasance. We consequently argue that the "competition" happens between two options in each group while obligation denial and prepayment have different triggering conditions. The principles are thoroughly explained by creating our theoretical framework in Chapter Five. To provide a brief introduction, the termination options we consider are defined below.

Default Options

Default may occur when a property value is smaller than its mortgage value (i.e. negative equity) or a borrower faces a problem of insolvency. A borrower surrenders his collateral property breaching his mortgage obligation. The decision to default has been regarded as the compound of European put options in existing literature (Epperson et al (1985) [65]). Since this analogy has obscured consequential repetition of option purchases and the correlation between options, we re-define default options as an **American put installment option**. In short, mortgage default can be viewed as a series of default options which expire at every payment date until scheduled mortgage payments cease. Borrowers (i.e. option buyers) normally do not default at the first payment date. When they make the first payment, they make an installment to continue a put option which represents the possibility to default at the next payment date. If borrowers exercise the put option, the mortgage is early terminated by the decision to default. Otherwise, once borrowers make another payment, the put option still keeps alive.

Mortgage Restructuring Options

Restructuring is a mutual agreement between a borrower and a lender to terminate an original mortgage contract and then redesign a new contract which may extend maturity and / or reduce the charged interest rate based on the amount that a borrower still owes to the lender and its financial ability to repay periodically. This alteration is viewed as an **exchange options** between mortgages with different cash flow streams.

Options of Full Prepayment in Cash

So far previous literature describes the decision to prepay as a call option. A borrower basically considers full prepayment in cash when market interest rates are lower than the agreed mortgage rate and a new refinancing rate would then be lowering the service charge. This is analogous to the exercise of an American call option. However, as the fixed exercise price is designed for a single call option, this does not represent the most appropriate analogy to model the exercise price that varies depending upon the remaining balance of the mortgage. We argue that full prepayment in cash should be analogous to an **American call installment option**. Borrowers make scheduled payments, that means they pay installments. If they prepay prior to the maturity of the mortgage, the call option is early exercised. No further installments are paid. The mortgage is early terminated through full prepayment in cash and a prepayment penalty is also charged as a result.

Defeasance

Defeasance refers to the process by which a mortgage is replaced with Treasury securities that are able to replicate the remaining cash flow pattern of the mortgage contract and concurrently the collateral property is refinanced or redeemed.

Defeasance is modelled as an exchange option between a mortgage and a riskless debt by Dierker et al. (2005). We convene with this formulation and treat it as an **exchange option between two assets with different liquidity** since a borrower switches his settlement method from "paying in cash" to "pledging Treasury securities".

1.3 Research Objectives

The primary aim of this study is to investigate the impact of collateral underlying property supply-constrained markets on early termination options of commercial mortgages. To address this main research question, we divide the study into three phases: (1) estimation of supply constraints of commercial real estate markets (in particular offices) by Metropolitan Statistical Area (MSA), (2) development of an option pricing theoretical model to value early termination options of commercial mortgages; and (3) empirical analysis of the impact of commercial property supply constraints on four types of early mortgage terminations.

Contribution 1: Estimation of Commercial Property Supply Constraints Supply constraints determine price responsiveness of supply and they play a key role in determining the price responsiveness of real estate cycles to exogenous shocks and the length and amplitude of boom and bust periods. The search and matching theory can be used to explain the short-run fluctuation of vacancy rate, rent and space absorption, alongside the market adjustment to long-run equilibrium. (Wheaton et al. (1994 [178], 1997 [179])) Cyclicality constitutes the short-run dynamics where the magnitude of amplification hinges on supply constraints. At present, the links between matching behaviour and supply constraints have not been examined. Therefore, we separately identify frictional, structural and cyclical vacancy following labour economics literature and construct a conceptual model to analyse the link between "economic mismatch" and supply constraints which are quantified by long-run supply elasticity. We show that mismatch situations and the search effort level affect the long-run relationship of demand and supply, as well as its short-run cyclicality. Simultaneously, an empirical model is used to estimate long-run supply elasticities of commercial real estate in 42 MSAs covering almost 60% of the US service related workforce and 50% of the entire population. The intuition is made that landlords control equilibrium vacancy through search and matching process and thus the supply elasticity is estimated precisely with the consideration of the search and matching process.

Contribution 2: Mortgage Termination Option Pricing Theoretical Model

We follow the prevailing approach to price options of mortgage default and prepayment by adapting Merton's and Black-Schole's models and assuming complete markets. Moreover, the competing risk model in the existing literature is employed to estimate default and prepayment risk simultaneously with the key assumption that both risks compete with each other. In fact, their likelihood contains the probability of negating the condition of the other termination option but it does not necessarily represent a situation of direct competition. In this part, we model the interaction between prepayment and obligation denial with installment options embedded with straddle or strangle like payoff (i.e. the option in which put and call options are longed and prepayment and denial obligation are analogous to call and put option respectively). Furthermore, it is the first study to consider installment options in valuation of prepayment (call installment options) and denial obligation (put installment options). Moreover, borrowers consider execution costs for these two options (i.e. bankruptcy costs for default and prepayment penalties for prepayment) during their decision making about early termination. Thus, we add execution costs to strike prices of underlying options for pricing early termination options. We also examine the impacts of property supply constraints on early mortgage termination options. The intuition in this part is that early mortgage termination is analogous to an American installment option embedded with straddle or strangle like payoff and its value is affected by property supply constraints. We offer insight in the linkage between mortgage markets and property supply constraints.

Contribution 3: Real Estate Supply Constraints and Early Termination Options

As a final step, we address a key research question with an empirical study on how collateral underlying property supply constraints affect choices of termination options of commercial mortgages. We develop the conceptual framework with a two stage approach which covers four types of early mortgage termination options. A multinomial logit model is employed in the first stage and logit models are applied in the second stage to analyze the behaviour related to early mortgage terminations. We directly use office supply constraints estimated in the first empirical work of this dissertation and identify its quantitative effect on the probability of early termination for default vs restructuring and defeasance vs prepayment in cash. The intuition is concluded that responses of four types of early mortgage termination on property supply elasticities are in different level. Our findings have policy implications because financial institutions could measure the portion of lending to more constrained supply property markets and regulators act on the relaxation / tightening of such constraints to manage mortgage risk at the systemic and or lender's level.

1.4 Thesis Structure

The thesis contains six chapters. This introductory chapter provides the background of commercial mortgages in the US, explains the motivation of our research with respect to early termination options and their link collateral underlying property supply constraints. The second chapter offers an overarching literature review on mortgage studies. In addition to offering a critical review of the existing literature for both theoretical models and empirical methodology, we identify niches for further studies and briefly explain our research direction that aims to fill in these gaps. In the following three chapters (3-5), we meet our research objectives in three key studies as described above. Lastly, the last chapter concludes our research findings and discusses meaningful risk management implications for policymakers, regulators and financial institutions.

Chapter 2

General Literature Review

2.1 Overview

The termination behavior of mortgages can be classified into three paths: default, prepayment, and defeasance. Default and prepayment of mortgages have been studied for over three decades, whereas the theoretical study of defeasance emerged in 2005 from Dierker et al. [59]. Despite the early development of research on the termination behavior of commercial mortgages, residential mortgages have dominated the theoretical framework and empirical work. The serious lag in the development of commercial mortgages can be attributed to the unavailability of commercial data, the lack of standardization of underwriting and reporting commercial mortgages, and the lack of a mortgage insurance market for commercial mortgages (Vandell (1993) [170]). Following the growth of the market for commercial mortgage-backed securities (CMBS) in the mid of 2000s, more standardized records of commercial mortgage deals have been stored, thus facilitating the study of commercial mortgages.

In the past three decades, the focal points of the study of early mortgage termination have shifted. In the meantime, the corresponding theoretical framework and empirical methodology have been enhanced to tackle more complicated research questions[1]. The initial focal point was to determine mortgage default risk in accordance with mortgage terms (e.g., loan-to-value [LTV] ratio and age of mortgage), financial condition of borrower, and collateral property age. When interest rates dropped, more prepayments in residential mortgages occurred. Academics attempted to broaden the study of prepayment behavior as a new focal point.

[1] The earliest study of complicated alternative mortgage products was done by Vandell (1978[167]) in which adjustable-rate mortgage, graduated payment mortgage and price-level adjusted mortgage were modelled.

Furthermore, a rapid growth of insured mortgage loan by government-sponsored entities (i.e., the Federal Housing Administration, which insured loans for home buyers, and Freddie Mac and Fannie Mae, which purchased the loan) raised concerns of catastrophic loss driven by mortgage default. This motivated the third main shift in the focal point in academia.

To facilitate the shifts in research focus, empirical modeling techniques were improved. For example, the competing risk model, such as multinomial logistic model, was constructed to investigate the likelihood among borrowers' choices, including the continuation of scheduled payment, default and full prepayment. This was not applied in the initial stage of study. In addition, proportional hazard model was employed to examine timing to default and relative risk of default. All shifts in research focus can be summarized into emphasis from three main perspectives (i.e. lenders, borrowers, and institutions). Notwithstanding changes from perspectives, mortgage default draws the greatest attention due to its impact on every party. In contrast, prepayment causes disturbance of scheduled payment, but there is no reduction of asset base. As a result, mortgage default dominates the studies of mortgage termination risk (Foster et al. (1984)[76], Quercia et al. (1992)[142]).

While this research focuses on the commercial mortgage, the related conceptual development is inspired by the theoretical framework rooted in the studies of the early termination of residential mortgages. This literature review thus criticizes the theoretical work in the studies of residential mortgages and compares the determinants of mortgage termination between residential and commercial mortgages. As a result, the following review is an overall critical analysis in terms of theoretical and empirical aspects separately and is presented as follows: (1) the role of securitization in mortgage markets, which is the key research topic in mortgage studies, (2) contributions to related theories and potential extension, (3) critique of empirical strategies in residential mortgage studies, (4) critique of overall empirical studies of commercial mortgages and (5) expected contributions of our research.

2.2 Key Research Topic: The Role of Securitization in Mortgage Markets

As the securitization of debts or mortgages prevails, more information of mortgage markets are released for analysis. The vast majority of mortgage studies focuses on the role of securitization in mortgage markets (Piskorski, Seru, and

Vig (2010[135]), Agarwal et al. (2011[5]), Arentsen et al. (2015[21]), Downs and Xu (2015[60]), Flavin and Sheenan (2015[73]), Fuster and Vickery (2015[77]), Han, Park, and Pennacchi (2015[100]), Rajan, Seru, and Vig (2015[144]), Floros and White (2016[74]), Gilje, Loutskina, and Strahan (2016[84]), Griffin and Maturana (2016[94]), Malkhozov et al. (2016[122]), Scheiser and Gross (2016[153]), Black, Krainer, and Nichols (2017[29]), Liu and Sing (2018[119])). For instance, the performance of securitized mortgages, particularly residential mortgages, is investigated by comparing them with bank-held loans in terms of mortgage default. Because the growth of the secondary market for a security can have an important incentive effect that affects the quality of the collateral behind the security itself, this affects the probability of mortgage default. Moreover, the role of securitization on debt renegotiation is also examined.

It is concluded that financial institutions are significantly more likely to extend portfolio loans than securitized loans. This is because frictions introduced by securitization create significant challenges to the effective renegotiation of mortgages. Furthermore, the characteristics of mortgage-backed securities are also studied. The effects of yield curves and term structure of interest rates on duration and convexity of mortgage-backed securities are analyzed. All of these studies imply that securitization plays a significant role in mortgage contract design and allocation of risk among borrowers, lenders, and investors. In particular, securitization played a pivotal role in the subprime mortgage crisis.

Before the crisis, rational mortgage borrowers were assumed and choices between fixed-rate mortgages and adjustable-rate mortgages could be optimized (Campbell and Cocco (2003[34])). In the aftermath of the subprime mortgage crisis, the rationality and financial sophistication of borrowers have been doubted, and a handful of research investigates the impacts of borrowers' literacy on mortgage choices (Gurun, Matvos, and Seru (2016[97]), Keys, Pope, and Pope (2016[117]), Van Ooijen and Van Rooij (2016[166]), Agarwal, Ben-David, and Yao (2017[6]), Agarwal, Chomsisengphet, and Zhang (2017[7]), Bhutta, Dokko, and Shan (2017[27]), Gathergood and Weber (2017[81])). They point out that less sophisticated borrowers make mistakes in choosing mortgage terms such as mortgage points, which allow borrowers to exchange an upfront amount for a decrease in the mortgage rate, term premium, and complex alternative mortgage products. More sophisticated borrowers, such as financial professionals, have lower delinquency rates. Thus, the mortgage crisis, particularly in the US, is more or less attributed to the financial sophistication of borrowers, but this may be different from the situation in Europe, where less sophisticated borrowers are more inclined to have traditional mortgages.

As the subprime mortgage crisis caused a unprecedented collapse of the financial system, more research studies discuss risk management to prevent enormous losses (Berg (2015[25]), Mian, Sufi, and Trebbi (2015[128]), Demyanyk and Loutskina (2016[53]), Goetz, Laeven, and Levine (2016[90]), Favara et al. (2017[70])). It is proved that effective risk management can help reduce default risk in spite of high operating costs that may reduce the benefits of risk management. Risk management measures include establishing mortgage companies by bank holding companies to transfer riskier mortgages to subsidiaries, strengthening the enforcement of the debt contracts related to investment and firms' risk, expanding the geography of bank holding companies, and implementing state-specific foreclosure laws. We, in this research, suggest an alternative risk management measure that is related to collateral. Collateral may involve some issues of asymmetric information related to property quality, property tax, and property investments in terms of repairs and maintenance (Anderson and Dokko (2016[19]), Stroebel (2016[159]), Melzer (2017[126])). All these issues would influence collateral values and decisions to early terminate mortgages. Therefore, we emphasize our suggested property price process for pricing early mortgage termination options.

2.3 Contributions to Related Theories and Potential Extension

The Black-Scholes option pricing model is the cornerstone of studying early termination options of mortgages in terms of default and prepayment. Defeasance option is viewed as an exchange option explained by Margrabe's model in which the principle differs from the Black-Scholes model. The first part of this section thus depicts the theoretical development of each mortgage risk and discusses the drawbacks. Suggestions for potential extension will be followed to fill in the gaps in the extant literature.

- **Default Risk**
  The decision to default is regarded as a compound of European put options (Epperson et al. (1985)[65]). In other words, default is merely considered when payment is due. If the property value is smaller than the mortgage value or insolvency occurs, a borrower will surrender the property and breach the mortgage obligation. This action is a so-called exercise of put option in which a borrower (i.e., option owner) sells the property to his lender (i.e., option seller) at varying strike prices that are determined by the remaining mortgage balance. Therefore, finding determinants of default

risk is related to estimating default option values.

The theory of pricing of risky corporate debt developed by Merton (1974)[127], which was an extension of the Black-Scholes option pricing model [28], became a cornerstone of the theoretical framework for mortgage default studies. Merton offered insight into the determinants of credit spread by disentangling unanticipated changes in the probability of default of corporation from unanticipated changes in interest rates. Credit spread derived from Merton's model is "company-wide" instead of focused on individual assets such as collateral; however, the framework is adopted in the mortgage default studies to find out the boundary condition of the decision to default. It should be noted that no transaction costs and taxes are assumed in Merton's and Black-Scholes' models. This is not realistic, however, and indeed transaction costs hinder the immediate exercise of options to default in spite of depreciation in property value that drops lower than mortgage value. This stimulates further theoretical development of nonruthless mortgage default by Foster, Van Order, and Vandell (Foster et al. (1984) [76], Vandell (1995)[171]). They verify that ruthless exercise for default cannot be expected and advocated for the consideration of transaction costs for the default risk model in empirical research.

Epperson, Kau, Keenan, Muller, and Vandell make contributions to establish the generalized theoretical model of mortgage default risk based on the seminal work of Merton and Black and Scholes (Vandell (1984) [168], Epperson et al. (1985) [65], Kau et al. (1995) [109]). Vandell developed the theoretical model for determining the probability of default of commercial mortgages by conditions of negative property equity and negative cash flow derived from net property incomes and concluded that default risk should be estimated in a multiperiod basis for capturing differences in the effect of default over time. When both boundary conditions of negative property equity and negative cash flow are satisfied, these translate into a double trigger and cause the exercise of the options. Epperson took a similar mathematical approach by constructing a partial differential equation to yield the solution of pricing default risk in residential mortgages in terms of house prices and interest rates. However, both pricing default risk models ignored the prepayment option with the argument support that there is no value in prepayment during a decline in interest rate; therefore, competing risk between default and prepayment (i.e., when the mortgage is prepaid, the likelihood of default is also simultaneously influenced) was not considered yet. Until the further theoretical development for evaluating the commercial mortgages was accomplished (Kau et al. 1987 [112] and 1990 [113]), the correlation between values of prepayment and default was captured by the valuation model. Prepayment negates the value of default, so prepayment ceases to be of value when default occurs. As a result, termination and boundary conditions for default would involve the condition when the prepayment value turns zero and the same token is also applied to prepayment.

Endogenous bias causes challenges to related studies, and the complex feedback mechanism shall be introduced to solve this concern. The underwriters require different thresholds in terms of LTV ratio, mortgage payment to income ratio, and mortgage terms, such as the amortization rate for different risk groups of borrowers. Meanwhile, borrowers simultaneously choose the most suitable mortgage design based on their own situations. Posey and Yavas (2001[139]) authored the first theoretical research to conceptualize the self-selection of the borrowers between adjustable- and fixed-rate mortgages by forming a separating equilibrium under asymmetric information in which the interrelation of borrowers' choices between two types of mortgages and feedback of lenders is captured into the model so that endogenous bias is eliminated. In other words, borrowers' choices can be used to determine their probability of default. A dynamic model of home mortgage default newly constructed by Campbell et al. [35] also helps to solve endogenous bias by applying a zero-profit condition for lenders and incorporating heterogeneity in borrowers' labor income risk to figure out optimal decisions with equilibrium mortgage rates. Apart from the emphasis on equilibrium of mortgage choices and mortgage rates, a handful of theoretical studies developed generalized collateral equilibrium models to explain credit rationing that address the interaction of collateral threshold and default likelihood. All their contributions perfect theoretical models for understanding default risk (Inderst et al. (2007)[107], Geanakoplos et al. (2014)[82]).

- **Prepayment Risk**
  The decision to prepay is regarded as a call option. When market interest rates for refinancing are lower than mortgage rates, a borrower will consider fully prepaying the loan. It is somehow an exercise of his call option to redeem the property at a varying payoff based on net equity values (i.e., property values minus remaining mortgage balance). Thus, prepayment risk is studied using the same option pricing approach as default risk.

However, in general, the development of the prepayment risk model lagged far behind the default risk model in the period of 1970-1990. The first theoretical research on prepayment penalty was published by Dunn and Spatt in 1985[61]. They explained the optimal strategy of banks with asymmetric information for designing mortgage contracts with respect to prepayment penalty to manage prepayment risk. Partial or full prepayment penalty critically depends on risk sharing between lenders and borrowers; therefore, prepayment risk is measured on the basis of risk sharing.

Following the phenomenal work by Dunn and Spatt, no proceedings for the development of prepayment model were delivered until the 1990s. A more complex prepayment risk model for distinguishing nonfinancial termination and financial termination was introduced by Kau et al. (1992)[114]. They embedded specific determinants that identified nonfinancial reasons, such as divorce or death of a family member, into the theoretical valuation model and then adopted different models (i.e., Poisson process for nonfinancial termination and stochastic process for financial termination) to describe the occurrence of different types of termination. This offered a new approach to illustrate the conceptual framework of how irrational behavior influences prepayment risk that cannot be explained by the option pricing model.

- **Defeasance Option**
  Apart from default and prepayment, defeasance is one of the paths to terminate a mortgage early by replacing a mortgage with US Treasury securities that are supposed to replicate the remaining cash flow structure of the mortgage to gain liquidity benefit and redeem the collateral (Dierker et al. (2005) [59], Murray (2011)[133]). The replacement is treated as an exchange, therefore, defeasance is regarded as an exchange option. The pioneering theoretical model of pricing an exchange option was developed by Margrabe [123]; however, Dierker and his co-authors did not refer to it but instead priced a defeasance option that is determined by prevailing interest rates, future rates of return generated by the released property equity, and the features of mortgage terms. Compared with both theoretical frameworks, the defeasance option based on Dierker's model critically depends on a correlation between unanticipated shock to property values and short-term interest rates, which is similar to one of the features related to the correlation between exchange assets found in Margrabe's study. Dierker also assumes, however, the constant credit spread of the borrower, which might violate Margrabe's proposition that discount bond values are stochastic un-

til maturity. A discrepancy in the estimated option values will be caused if different models are applied.

Overall, theories related to termination options, particularly default options, are well established and are deep rooted in options pricing theory. There is still room for further development, however, to depict more complex situations related to mortgage termination nowadays.

- **Concept of installment options embedded with straddle payoff and perfect substitute for shaping competing risk framework**
  The competing risk model describes an interaction between default risk and prepayment risk. As discussed, boundary conditions of default include the condition that prepayment options are not exercised and vice versa. The decision to default or prepay relies on the values of both options. If default option values are higher than prepayment, then a borrower will decide to default and vice versa. The straddle option (i.e., long call and put on the same underlying asset with same strike price) can describe this decision rule as default and prepayment as analogous to put and call options. The straddle option has the feature that the holder exercises either a call or a put as their triggering conditions are opposite. Moreover, we should consider the stream of mortgage payments. When the payment is made, the maturity of the early mortgage termination option (i.e., analogous to the straddle option) extends to the next payment date. That means the option remains alive when a regular mortgage payment is made. Thus, the early mortgage termination option should be analogous to the installment option embedded with a straddle-like payoff so as to precisely describe the decision rule between mortgage default and prepayment.

  When borrowers decide to prepay their mortgages, the ways to pay up the mortgages earlier would be thoroughly considered. Borrowers can choose between prepayment in cash and defeasance, hence redeem the collateral property in return. The former involves cash payment plus prepayment penalty, and the latter involves pledged Treasury securities and setup cost. Lenders do not bear reinvestment risk in the case of defeasance, but this concern will be raised if mortgages are terminated by full prepayment. Prepayment in cash and defeasance can be treated as a pair of perfect substitutes for the decision to prepay the mortgages. On the other hand, when borrowers are near insolvency, they struggle between default and mortgage restructuring. Both lead to early termination of the original mortgages, but obviously loss of lenders would be reduced under mortgage restructuring compared with default. In summary, choices between prepayment in cash and defeasance, and between default and mortgage restructuring, are two pairs of perfect substitutes. It is because borrowers only throw themselves into either path of ending up the original mortgages in each extreme situation. Indeed, it is a critical issue in the lenders' interest; however, the existing competing risk model merely captures the interrelation between prepayment risk and default risk and does not consider the installment option and two pairs of perfect substitutes. Therefore, an extension of the competing risk model will be valuable so as to dissect the risk of early mortgage termination in a deeper sense.

- **Introduction of collateral underlying supply elasticity to model the property price movement process**
  The probability of early termination is determined by the change in collateral property price, the financial and nonfinancial situation of the borrowers, and the mortgage terms. Most literature (e.g., Epperson et al. 1985[65], Kau et al. 1987[112], 1992[114], 1995[111]) describes property price movements using simple stochastic processes such as geometric Brownian motions (and rarely modeled by Poisson processes). The general movement process is not simulated in the ground of property market dynamic in a precise way that causes a loss of important information to explain the variation of early termination behavior by property markets. The property market dynamic relates to the property supply constraint and real estate cycle. Hilber and Vermeulen (2016[105]) studied the impact of property supply constraints on property price and concluded that property price responsiveness is restricted to supply constraint. That means less vigorous change in property price by a certain level of property demand shift is seen in less supply-constrained markets compared with more severe supply-constrained markets. The elasticity of collateral property price to supply can quantify the degree of supply constraints. As frequency of early mortgage termination varies by collateral underlying property markets, and we do not only consider property demand factors for investigating early mortgage termination, it is necessary to introduce supply elasticity to model the price movement process for estimating the probability of early mortgage termination. Furthermore, a supply constraint is exogenous to the decision of mortgage termination, which also helps to solve endogenous bias. As a result, the extension can contribute to solving one of the greatest concerns

in the related studies.

2.4 Critique of Empirical Strategies in Residential Mortgage Studies

The theoretical framework has evolved from the pure default risk model into the competing risk model for capturing the interaction of likelihood of default and prepayment as well as conceptual framework of defeasance options. Different theoretical framework stimulates the formation of different empirical strategies, which are used to find empirical evidence and hence justify the related theoretical framework. The exception is that there is no empirical study of defeasance. In general, empirical studies can be divided into three approaches that are merely default or prepayment focused and a dual purpose for studying both default and prepayment. Despite different approaches, findings related to transaction costs reach a consistent conclusion; however, inconsistency is found in the influence of heterogeneous factors. In this part, we would critically discuss the empirical strategies implemented in residential mortgage studies.

- **The empirical models in which transaction costs are involved are questionable**

  The impact of transaction costs on early mortgage termination is widely explored (Kau et al. (1993[110]), Quigley et al. (1995[143]), Ambrose et al. (1998[11]), Deng et al. (2005[54])). Their strategies involve option pricing models that are based on the assumptions of a perfect capital market where no transaction cost is supposed. Simulation coupling with empirical modeling (i.e., hazard model and competing risk model) are carried out to quantify the friction driven by transaction costs, reputation costs, and costs of moving house. This examines the impact of friction on the likelihood of default and refinancing after being fully prepaid by comparing models with and without friction. Although their findings reach a consistent conclusion (i.e., the friction avoids borrowers from defaulting, and higher transaction costs suggest higher mortgage value and hence imply a greater likelihood of refinancing), their strategies by simple substitution of transaction costs into the frictionless model are questionable. This is because the more complicated interaction of transaction costs with other variables, such as mortgage value, is neglected. Then, the impact of transaction costs on early mortgage termination may be misestimated.

- **Inconsistent performance of models with unobserved heterogeneity**
  Heterogeneity can be driven by differentials of transaction costs, income, wealth and risk level of borrowers, and collateral underlying housing market dynamic. Furthermore, heterogeneity can be distinguished as unobserved and observable. Wealth and risk of borrowers as well as certain features of housing market are unobserved (Deng et al. (2000[55]), Ambrose et al. (2001a[12] and 2001b[14]), Agarwal et al. (2006[4]), Clapp et al. (2006[49]), Pennington-Cross (2010[134])). Competing risk models, including hazard and multinomial logit models with unobserved heterogeneity, are the most frequently applied empirical strategy. Deng, Quigley, and Van Order were the pioneers to formulate this strategy and figure out that the inclusion of unobserved heterogeneity classified by the risk level of borrowers is crucial for studying prepayment risk but does not matter for default risk. However, subsequent empirical studies do not yield compatible results that competing risk models without unobserved heterogeneity had greater explanatory power for prepayment risk than those with unobserved heterogeneity. This is because different choices, including move, refinancing after fully prepaid and default, were considered or only default was examined in ignorance of prepayment, which was different from the leading empirical studies (Clapp et al. (2006) and Pennington-Cross (2010)). Furthermore, the difference in the time span of data (i.e., mortgages issued in 1976-1983 are studied in Deng et al. (2000), Ambrose et al. (2001a) focuses on mortgages originated in 1989, while Agarwal et al. (2006), Clapp et al. (2006), and Pennington-Cross (2010) select mortgages originated in 1994-2001, 1993-1994, and 2001-2005, respectively.) and data dimension (i.e., cross-sectional data in most studies instead of panel data used by Deng et al.) are also attributed to this divergence. As a whole, it is hard to conclude the impact of unobserved heterogeneity on mortgage termination risk.

In conclusion, empirical strategies formulated in the residential mortgage studies so far strive for mitigating concerns about models that are detached from reality. Of which, endogeneity bias owing to interaction between foreclosure (i.e., a procedure for mortgage default) and house price movement, as well as its contagion effect across neighboring areas, is successfully eliminated by identifying the foreclosure effect with repeated sales method and estimating contagion discounts to house price (Harding et al. (2009[101]), Campbell et al. (2011[36])). Furthermore, interaction between default and prepayment driven by direct and indirect effects of prepayment penalties or prepayment restrictions on early mortgage termination are also studied (An et al. (2015[17]), Fuster and Vickery (2015[77]), Steinbuks (2015[158]), Quercia, Pennington-Cross and Tian (2016[141]), Beltratti, Benetton, and Gavazza (2017[23])). That means interactive relationships between different types of early mortgage terminations cannot be neglected. These concerns are also raised in the commercial mortgage studies. As a result, the residential mortgage studies offer fascinating insight for commercial mortgage studies, and, indeed, certain similar approaches are seen in the existing literature on commercial mortgages.

2.5 Critique of Empirical Studies of Commercial Mortgages

Akin to the study of residential mortgages, the empirical studies and simulation analysis of commercial mortgages can be also categorized into a single focus on default, prepayment, or defeasance and into a dual purpose for simultaneously studying more than one termination option. The striking contrast is exhibited in the study of defeasance that is never discussed in residential mortgages but is exclusively found in commercial mortgages because defeasance is a special covenant stipulated by commercial mortgage lenders. Due to data limitation, less academic contributions to the studies of commercial mortgages are found. This is also the reason there is no empirical research on defeasance to examine causation and merely a handful of simulations work for estimating defeasance options in addition to sensitivity tests to change the LTV ratio and credit rating of CMBS loans (Akat et al. (2012[9]), Varli and Yildirim (2015[173])). Mortgage default also dominates in the termination risk studies of commercial mortgages. Regarding the default studies, a double trigger by negative equity value of property and insufficient cash flow is one of the main research focuses because a double trigger is vindicated as the key driver of commercial mortgage default, followed by transaction costs and tax considerations. Sometimes originators and special servicers may be able to implement austerity measures related to mortgage restructuring to stimulate a turnaround when borrowers come close to default. Therefore, the related impact of originators and special servicers on mortgage default has been investigated (Vandell (1992[169]), Vandell et al. (1993[172]), Episcopos et al. (1998[64]), Archer et al. (2002[20]), Ciochetti et al. (2002[44], 2003[45] and 2007[46]), Goldberg et al. (2002[91]), Grovenstein et al. (2005[95]), Titman et al. (2005[161] and 2010[163]), Seslen and Wheaton (2010[154]), Cho et al. (2013[43])). Concerning prepayment, the decision to prepay heavily relies on changes in market interest rates and transaction costs; therefore, related prepayment studies are discussed in these aspects (Abraham et al. (1997[1]), Follain et al. (1997[75]), Ciochetti et al. (2002[44] and 2003[45]), Ambrose et al. (2003[15])). Compared with the studies on residential mortgages, there is less empirical investigation on geographical variation of default rates or prepayment rates in commercial mortgages and a lack of delineation in how property market dynamic interacts with the early termination of commercial mortgages. However, the theoretical framework about termination options has necessitated empirical proof of this interaction. In summary, the overall development of commercial mortgage studies has not been well established so far.

Despite the concept of competing risk between default and prepayment that emerged in the late 1980s (Hendershott et al. (1987[103])) and well developed in the early 2000s, the investigation of interdependent risk between them has not prevailed. In contrast, the single approach for studying either default or prepayment is still in the majority among recent studies (An, Deng, Nichols, and Sanders (2013[16]), Chen and Deng (2013[37]), Cho, Ciochetti, and Shilling (2013[43]), Liu and Quan (2013[120]), Tong (2014[164])). This phenomenon is supported by relatively weak findings of competing risk in the termination of commercial mortgages compared with residential mortgages. Merely, Ciochetti and Ambrose separately proved the joint nature of call and put options was embedded in mortgage default and prepayment based on around 2,600 mortgages held in the life insurance company and around 4,300 securitized mortgages. It can be argued, however, that a much smaller sample size (i.e., not more than 5,000 cases in most studies, which roughly represents three percent of the commercial mortgage markets) cause severe censoring problem and hence cannot bring a strong evidence of competing risk. Given the enhancement of data coverage and availability, more phenomenal empirical research under the framework of competing risk model will be conducted.

The data sources for commercial mortgage research can be classified into three types: anonymous life insurance companies, Fannie Mae and Freddie Mac, and CMBS database providers. The life insurance companies provide data about commercial and multifamily mortgages held in their portfolio. Fannie Mae and Freddie Mac merely offer multifamily mortgage data. The main CMBS database providers are Trepp, Morningstar, Intex, and Bloomberg, all of which provide securitized commercial and multifamily mortgage data. Trepp database even covers nonsecuritized mortgages. Accessibility of data from the life insurance companies is restricted and only offered with the consent of a certain single insurance company. As a result, it is impossible to obtain a significantly large data size from insurance companies. In contrast, data from Fannie Mae and Freddie Mac, as well as CMBS database providers, are available to public upon purchase. According to the Mortgage Bankers Association, 35% of commercial and multifamily mortgages are held by government-sponsored entities (GSE) and CMBS and collateralized debt obligation issuers in total. In other words, usage of GSE-provided data and the CMBS loan database can help conduct more comprehensive studies rather than data from life insurance companies, as only 13% of commercial and multifamily mortgages are held by them[2].

In terms of data dimension, life insurance companies and Bloomberg can provide cross-sectional data, but the remaining data sources offer panel data. There is no doubt that panel data are more helpful when certain mortgage terms and LTV ratio, as well as debt service coverage ratio (DSCR), etc., are time-varying. Regarding database coverage, Trepp and Bloomberg obtain detailed information of each securitized mortgage, including every mortgage term and collateral detail, by zip code level and collateral underlying tenancy; however, only Trepp provides longitudinal data as mentioned. In general, academic researchers have tended to use the CMBS loan database instead of data from the life insurance companies due to the higher reliability and more comprehensive data coverage.

The estimation and analysis can be divided into two streams: the finance mathematical model for simulation and the econometric model for empirical strategies. Regarding the finance mathematical model, because of the framework of option pricing theory, the contingent claim model by the Monte Carlo method is applied to estimate the related risk premium and timing to default or prepayment (Titman et al. (1989[162]), Riddiough et al. (1993[145]), Childs et al. (1996[41] and 1997[42]), Kelly et al. (2001[116])). Different estimates of option value were yielded in cited research due to different assumptions on unobservable costs driven by transaction, cross-default clauses, and prepayment penalties.

Concerning econometric models, the binary logistic model, multinomial logistic model, and hazard model are the main methods to investigate mortgage termination behavior. The binary logistic model considers two outcomes and is most frequently employed in default studies that mainly discussed the impact of a double trigger (coexistence of negative property equity and negative cash flow) and tax consideration on likelihood of default (Episcopos et al. (1998[64]), Archer et al. (2002[20]), Goldberg et al. (2002[91]), Cho et al. (2013[43])). The multino-

[2]Unsecuritized mortgages issued by commercial banks account for about 50% of commercial and multifamily mortgages.

mial logistic model is used to predict the probability of more than two discrete outcomes. This is a type of competing risk model to study the interaction of default and prepayment. The competing risk hazard model with unobservable heterogeneity is even more complicated. Hazard models are applied for examining time to default or prepayment, which is the preferable approach for analyzing how originators and special servicers influence default risk (Ciochetti et al. (2003[45]), Black et al. (2012[30]), Chen et al. (2013[37])).
In general, a wide variety of datasets and methodology employed in existing literature result in inconsistent findings, and this pushes controversial debates about the main determinants of mortgage risk. The debate is discussed below. On the contrary, geographical variation of default and prepayment risk was overall concluded with consistent estimation results. Thus, it implies that the in-depth dissection of termination risk at the geographical level will be insightful and more reliable results will be expected.

- **Endogenous underwriting process leads to inconsistent explanatory power of LTV ratio and DSCR**
  The problem of endogeneity arises from underwriters who would determine thresholds of LTV ratio and DSCR at origination for risk management. Academic researchers suggest different methods for solving this endogenous concern. For instance, Archer[20] captured more detailed multifamily mortgage terms as well as collateral characteristics as a proxy of risk management by underwriters; hence, the LTV ratio and DSCR were supposed to explain unexpected default. Ambrose [15] adopted an approach similar to Archer for securitized commercial mortgages and omitted DSCR as an independent variable. Grovenstein et al. [95] tried to deal with endogeneity by replacing the original LTV ratio and DSCR with pricing margin. Seslen and Wheaton [154] replaced the LTV ratio and DSCR at origination with contemporaneous ones to solve the endogenous concern with the argument that contemporaneous LTV ratio and DSCR are not controlled by underwriters and therefore are decoupled from the status at origination.

  The first two approaches might not completely solve this problem and, in contrast, generated astonishing findings that there is no relationship between LTV ratio and probability of default or prepayment. However, the majority of studies that captured similar mortgage terms, but employed different models other than the competing risk model used by Archer and Ambrose, verified significantly the positive relationship of LTV ratio with the probability of default or prepayment and the secondary importance of

DSCR. In convention, endogeneity is solved by an instrumental variable approach or by constructing a system of simultaneous equations. The existing literature does not tackle the concern of these approaches, and there are no clear strategies for identifying endogeneity; thus, it is hard to justify the explanatory power of the LTV ratio and DSCR at origination until the most appropriate strategy is formulated. As a result, such core determinants of default or prepayment risk cannot be ascertained.

- **Inconsistent conclusion about LTV ratio and DSCR results in possible mistakes of double triggered default**
  The justification of a double trigger may not be affirmed in the controversy of the explanatory power of LTV ratio and DSCR at origination. Goldberg et al. (2002[91]) and Vandell et al. (1993[172]) confirmed the significant impact of joint probability of negative equity and negative cash flow on mortgage default by simulation and empirical modeling, respectively. However, both joint functions of a double trigger consist of LTV ratio and DSCR as inputs. If the relationship of LTV ratio and DSCR with mortgage default or prepayment cannot be verified (as discussed above), then the statistically significant impact driven by a double trigger will be still questionable.

- **Inconsistent findings of secondary determinants of prepayment risk**
  Undoubtedly, changes in market interest rates are the primary determinant of prepayment risk. The discrepancy of statistical significance of secondary determinants, including collateral property type and expiration of lockout provision, is found in related studies. Regarding collateral property type, Ciochetti[45] attained insignificant results for explaining prepayment by property type, whereas Ambrose[15] found that mortgage collateralized with office property bears a greater prepayment risk but hotel collateral helps reduce prepayment risk. The difference can be attributed to different mortgage pools: the former is the mortgages held by the insurance company that contain a much longer history starting from the 1970s and the latter is securitized mortgages whose time period is restricted to the 1990s and 2000s. On the other hand, Selsen and Wheaton[154] found that the expiration of the lockout provision can significantly explain the prepayment risk with a positive relationship. This finding is inconsistent with the results estimated by Ambrose. Selsen and Wheaton modified the multinomial logit model with a loan age fixed effect so as to measure the probability of prepayment or default based on performance in the last time period rather

than the simple multinomial logit model applied by Ambrose. In addition, delinquency was also pooled in the outcome of default by Selsen and Wheaton, but Ambrose did not do so. Therefore, extreme inconsistency is exhibited in the impact of prepayment provision terms on prepayment risk.

In general, the endogenous problem and data from a variety of data sources result in inconsistent findings related to termination risk of commercial mortgages. The existing literature has not provided the best solution for dealing with the endogenous problem; hence, even the explanatory power of core determinants (i.e., LTV ratio and DSCR at origination) lack consensus. In addition, unobserved heterogeneity has not been in-depth examined in commercial mortgages while there is a growing number of related empirical studies in the residential mortgages. Heterogeneity can be driven by a differential of special service process and originator decisions as well as collateral characteristics. The first two have been investigated (Chen et al. 2013[37], Titman et al. 2010[163]), but there is lack of insightful over empirical research for examining the last one. Heterogeneous collateral characteristics can be caused by geographical discrepancy, collateral underlying property market, and variation of tenancy of collateral property. Apart from the demand factors of property market, others are not thoroughly examined when studying the termination risk of commercial mortgages. Furthermore, default studies dominate the existing literature, and there are only two simulation studies about defeasance option (Akat et al. 2012[9], Varli and Yildirim 2015[173]). However, when property value has been climbing in the near future, more exercises of defeasance option can be foreseen. Related empirical study will offer fascinating insight to originators or investors. There is a lot of room for enhancement in terms of advancement of methodology, research focus and extension of theoretical concept.

2.6 Expected Contributions of Our Research

To contribute to the literature in the field of early termination risk of commercial mortgages, we will deliver an original idea to extend the existing theoretical framework. The first conceptual idea relates to installment options and perfect substitutes for shaping the competing risk framework, as discussed in Section 2.3. Early mortgage termination is analogous to an installment option embedded with a straddle-like payoff. The borrower can choose default (put) or prepayment (call) options to maximize the value of early mortgage termination. We apply this analogy in Chapter Four to build the theoretical model.

All five outcomes-defeasance, prepayment in cash, continuation of scheduled payment, mortgage restructuring and default-will be considered in the new concept developed in Chapter Five, in which a two-step decision process is conceptualized as the two-stage option pricing theoretical framework. The first step involves three options: surrendering the collateral, continuing scheduled mortgage payment and redeeming the collateral. The second step is to consider which way to surrender the collateral or to redeem the collateral in each extreme situation; therefore, mortgage restructuring and default is the pair of perfect substitutes for the way to deny the obligation and to surrender the collateral, and defeasance and prepayment is another pair of perfect substitutes for the approach to redeem the collateral. The new framework depicts this decision process. On the other side, property supply elasticity is introduced into the theoretical framework. The reasoning is discussed in Section 2.3. The property price movement process is modified by bounding with supply elasticity, that is in line with the restriction of price responsiveness by supply constraints. This helps to model mortgage termination risk with greater attachment to real property market dynamic. To precisely estimate the long-run supply elasticity for modeling mortgage risk, we attempt to empirically identify the mismatch between landlords and tenants that causes disequilibrium in the commercial property market. This is the main contribution to the research field of property supply constraints because extant empirical studies do not cover commercial real estate. To conclude, we expect the study sheds light on pricing commercial mortgage risks and quantifying commercial property supply constraints.

Our key hypotheses include: (1) the supply of commercial property markets is highly inelastic because of zoning and, more importantly, structural vacancy; landlords may intend to keep property vacant so as to seek "targeted" tenants, (2) positive correlation between supply elasticity and structural vacancy offers an alternative indicator for measuring supply constraints, and (3) impacts of property supply constraints on four types of early termination options, which are significant. Mortgages collateralized with properties in supply inelastic areas are more likely early terminated through the denial of obligations.

Based on our estimation results of the long-run supply elasticity of office markets in 42 metropolitan area, all markets are supply inelastic. Office rent response is more sensitive to change in mismatch rate compared with fundamental demand factors (i.e., increase in the rate by 1% reduces real rent by 0.02-0.7%.) This finding verifies our first hypothesis. For the second hypothesis, we have yielded a positive correlation between supply elasticity and structural vacancy as hypothesized. The third hypothesis have been also verified in the third research, thus the important role of property supply constraints in determining the likelihood of early mortgage termination is proved.

Chapter 3

Supply Elasticity and Search Equilibrium in Office Markets

3.1 Abstract

In the current shift from fixed to flexible office space demand, we focus on the offer response to demand changes by presenting a new conceptual model for the estimation of office supply elasticity in commercial real estate markets. We transfer concepts from labour economics to define frictional and structural vacancy and develop a theoretical framework where the presence of physical and economic mismatch leads to either permanent or temporary levels of vacant space within a fundamental real estate cycle model.

Empirically, we identify economic mismatch by observing landlords who re-let occupied space. Estimating an error correction model with 4 simultaneous equations, we determine the long-run equilibrium and matching process from short-run disequilibrium to estimate elasticity and structural vacancy rate in 42 Metropolitan Statistical Areas (MSAs) covering almost 50% of the entire US population and 60% of the office workforce. We find that MSAs are supply inelastic and our results are consistent with previous studies in housing markets. We also prove that the search and matching process is significant and improves the ability to explain our results. Finally, a positive correlation between estimated supply elasticity and structural vacancy implies that the low controlling power of landlords reduces the flexibility in adjusting equilibrium vacancies to respond to market shocks, thus supply elasticity is likely to be explained entirely by geographical and regulatory constraints.

3.2 Introduction

The price responsiveness to property supply always draws great interest among policy makers, particularly in the literature investigating house price bubbles. Over the last decade, we have witnessed a revolutionary shift in the nature of office space demand from individual offices to collaborative space. On one hand, all major corporations (e.g. Facebook, Google, Ernst and Young, PricewaterhouseCoopers) have been advocating for open and shared workspace and adopted work-from-home policies. On the other hand, smaller companies (especially ventures and sole traders) have been using shared office facilities to efficiently maximize networking opportunities offered by new providers of workspace. Moreover, less demand in office space is foreseen when more on-site tasks are assigned and more tedious work is superseded by automation. Facing all these changes, the ability of supply to adjust to new requirements and temporary mismatch (hence the presence of supply constraints in the office sector) can be used to predict the impact of a negative demand shock on property prices.

Supply constraints are generally classified into two main categories: regulatory and physical. Regulatory constraints are measured by the tightness of the development approval process, which is usually identified through surveys (Gyourko et al 2008 [99], Saks 2008 [150]). Saiz 2010([149]) introduced a new empirical strategy where land unavailability is measured to solve the endogenous problem, identifying the tightness of both regulatory and physical constraints of housing supply. Overall constraints are quantified by supply elasticity, which is mostly estimated using an urban growth-based econometric model.

We may argue that supply elasticity for offices should be positively correlated with the one in housing markets because the tightness of planning regulation and geographical barriers should not differ within the same area. However, lacking empirical evidence for non-residential markets, different dynamics of market competition between suppliers and divergent incentives to control the restrictiveness of supply constraints between different property markets motivate the focus of our study in office supply elasticity by metropolitan statistical area (hereafter MSA).

In fact, the higher proportion of informed investors in the office sector compared to the residential markets leads to a “strategically managed” availability of office space supply. In equilibrium, supply could be influenced by investors’ approach to control the flow of available office space as their strategy is rooted in the search and matching theory, initially applied in housing markets by Wheaton (1990[175]). Since lease contracts are long-term and have fixed rents, landlords strategically keep aside a predefined amount of vacant space for high-profile tenants who will afford higher rents in the future, maximizing their profits. This amount of space may also vary over boom and bust cycles.

In our research, we define this situation as *economic mismatch* where a bid-ask rental gap exists until landlord and tenant's requirements match and the vacant space is occupied. This mismatch situation may also be present in a long run equilibrium increasing the *natural vacancy rate*. Simultaneously, the vacant space in non-prime (i.e. class B or C) office buildings is due to its old-fashioned and worn-out physical design that requires a refurbishment to reach prime quality before their use can be guaranteed. We define this phenomenon as *physical mismatch* and we argue that it can also increase the long-run natural vacancy rate due to long lease terms (even above 5-6 years) locking in tenants for predefined time periods in sometimes physically mismatched space. Unlike in housing markets where households act as both buyers and sellers and the searching process mainly affects the short-run disequilibrium, office landlords (i.e. sellers of a space rental service) with higher controlling power are capable of altering the long-run equilibrium of supply. As a consequence, we believe that equilibrium vacancy is highly important because it may distort the responsiveness of rents to office supply.

Moreover, the analogy of real estate and labour markets (where a well-established search and matching model can be applied) helps us to transfer the concept of unemployment to unoccupied space, distinguishing three types of vacancy: cyclical, structural and frictional. This set up also sheds light on the three components driving long-run vacancy: mismatch rate, search effort level (for structural) and demand of refurbishment (for frictional). We find that a search equilibrium does exist and we show that equilibrium vacancy should be determined at the time of the search equilibrium.

We initially build a conceptual framework to link supply elasticity and long-run vacancy. We then suggest an empirical strategy to identify economic mismatch (i.e. space in use which is available for re-let to new tenants instead of existing tenants), to quantify the search effort (i.e. relative size of available letting space listed), and to determine a simultaneous equilibrium in the market and the search and matching process using an error correction model.

Our empirical findings support the argument that a search equilibrium is essential to estimate office supply elasticity, which is found to be positively correlated with structural vacancy. As low structural vacancy implies less control by landlords, we argue that the price responsiveness to supply changes is almost completely explained by regulatory and geographical issues when office sectors are supply

inelastic.
This chapter is organized as follows: the next section provides a literature review related to supply constraints, vacancy and search equilibrium; section 3.4 presents our conceptual model. In section 3.5, we explain our empirical strategy including data description and error correction model framework. Sections 3.6 and 3.7 include main results, robustness tests and a discussion about supply elasticity rankings by MSA. Finally, we draw our conclusions and present further research directions in the last section.

3.3 Literature Review

Property supply is a crucial factor in property market dynamics together with demand shocks and, as a result, we find a growing number of studies on supply constraints and their policy implications. However, as the variation of supply elasticity by city/municipality is found significant, a data shortage for commercial property markets exists globally, so the main literature focuses on US housing markets. Green et al. (2005) [92] argued that the variation of supply elasticity among 44 MSAs is explained by the difference in local regulation. Saiz (2010) [149] suggested an empirical strategy to prove Green et al.'s (2005) argument, to solve the endogeneity issue, and to identify physical and regulatory constraints for 95 MSAs by quantifying land unavailability through Geographical Information System (GIS) and referring to the Wharton residential land regulatory index. Wheaton et al. (2014) [176] provided a unique approach, merging the stock-flow framework and urban growth theory to disentangle the short-run disequilibrium from the long-term trend of housing prices and to estimate both long-run and short-run supply elasticities for 68 MSAs.
Furthermore, large-scale surveys on the planning approval process are used to measure the stringency of regulatory supply constraints using intensive resources and well-designed questionnaires to mitigate the "selection bias" in information disclosure by interviewees. So far, the Wharton Residential Land Use Index compiled by Gyourko et al (2008) [99] and the Saks's composite index (2008) [150] are frequently cited and the most influential measures. The former consists of 11 sub-indices regarding political pressure, ease of zoning approval, supply, and density restrictions for 293 MSAs. Data was collected through the largest survey where planning directors of around 2600 municipalities were interviewed in the 2000's. Because of the high response rates, the dataset represents the most reliable measurement of regulatory constraints to date. The latter, instead, was constructed by taking the average of six independent surveys related to the processing time

of zoning approval, severity of population growth controls, protection of historic sites and environmental regulation conducted for 83 MSAs between 1975 and 1990. Although Saks covered fewer MSAs, the index is considered robust and often cited in the literature.

Table 3.1 exhibits the Spearman rank correlation matrix of the five main regulation indices, estimations of supply elasticities in the US housing markets, and two versions of our measure for offices. Since some measures refer to elasticities and others to constraints, we report absolute values to make the comparison easier[1]. In general, findings for housing supply constraints are consistent. Overall, correlation coefficients of Saiz's supply elasticity with other indices (except for Wheaton's long-run supply elasticity) are the highest, followed by the Wharton index. This evidence may be attributed to similar methodologies adopted by Saiz (2010), Gyourko et al. (2008) and Saks (2008). Since Green et al. (2005) and Wheaton et al. (2014) applied different methods relatively lower correlations are found. Finally, the correlation coefficients of our estimated office supply elasticity with these studies (last two rows and columns) show consistency with previous housing market measures (further discussion will be included in Section 3.7).

[1]All coefficients have expected signs: positive between two measures of elasticity (or constraint) and positive between an elasticity measure and an inverse of regulatory constraint index

Table 3.1: Spearman Rank Correlation Matrix of Supply Elasticity between Housing and Offices in the US

	WRLURI	**Saks**	**Green**	**Saiz**	**Wheaton(LR)**	**Office(With RSI)**	**Office (Without RSI)**
WRLURI	1						
Saks	0.552***	1					
Green	0.357**	0.511***	1				
Saiz	0.545***	0.613***	0.627***	1			
Wheaton(LR)	0.435***	0.368**	0.331**	0.370***	1		
Office(With RSI)	0.371*	0.284#	0.122	0.121	0.141	1	
Office(Without RSI)	0.421***	0.460***	0.242	0.239#	0.449***	0.818***	1

Notes: WRLURI and Saks are regulation indices measured by number of standard deviation of regulatory restrictiveness in housing markets (greater value indicates looser regulation), others estimate housing supply elasticity. For Saiz index, supply elasticity is presented in 2 decimal places. Data is slightly adjusted by extrapolation when same figures are shown but in different ranks. LR denotes "Long Run" elasticity respectively. Signs ***, ** and * as well as # represent significant results at 1%, 5%, 10% and 20% level respectively.

Compared to housing markets, regulatory constraints in commercial real estate curtail fiscal revenues to a greater extent, but they reduce negative externalities such as congestion and pollution. As a result, the restrictiveness of supply constraints in commercial property markets is even more driven by local circumstances when local governments attempt to reconcile their fiscal need with concerns for the living environment (Fischel 1973 [72]). Since commercial data is hard to access, rare empirical studies on supply elasticity are found in non-residential markets. Benjamin et al. (1998) [24] are an exception and studied retail space supply elasticity for 34 MSAs, distinguishing short- and long-run by adopting a stock-flow model. Since an endogenous cycle driven by longer production lags and lease terms in commercial markets adds complexity to the structure of housing ones, the short-run disequilibrium shall not be ignored as a biased estimation of supply constraints may be obtained. Moreover, a stock-flow model proves to be the appropriate approach to disentangle the short-run disequilibrium from the long-run state.

So far, a causal relationship between supply constraints and vacancy is not considered to estimate supply elasticity. Only two aforementioned studies - Benjamin et al. (1998) [24] and Wheaton et al. (2014) [176] - implicitly involved imbalances between supply and demand by using a stock-flow model where vacancy is captured in the estimation of supply elasticity. Cheshire et al. (2018) [38] filled this gap and showed that tightening regulatory constraints on housing markets in the UK significantly increased vacancy rates because inflexible planning hinders the matching process - i.e. demand for housing characteristics is satisfied. Furthermore, they point out that in office markets an increase in price volatility motivates landlords to keep properties empty since the value of real options (e.g. option to defer) increases. Fluctuations in vacancy rates driven by mismatch hinge on supply constraints and may function as an alternative test on the plausibility of supply elasticity estimates. Hence, importantly, equilibrium vacancy has to be considered.

When markets clear, an equilibrium is reached but the vacancy rate may still not be necessarily equal to zero. Academic researchers have started to investigate equilibrium vacancy rates since the late 1980s. Most scholars - Rosen and Smith (1983)[148], Gabriel et al. (1988[78] and 2001[79]), Shilling et al. (1987)[156], Jud et al. (1990)[108], Englund et al. (2008)[63], Hendershott et al. (2013)[104] - have referred to it as natural vacancy, or the rate of unoccupied space where rents remain unchanged. Others - e.g. Wheaton and Torto (1988)[177], Sivitanides (1997)[157] - have referred to it as structural vacancy, but their definition and estimation approach - rental adjustment originally developed by Eubank and

Sirmans (1979)[66] - do not differ from the former. Moreover, frictional vacancy is discussed similarly to structural vacancy (Wheaton and Torto (1988[177]). However, if we fully transfer the concept of unemployment in labour markets to the one of vacancy in real estate markets, we may be able to better understand the role of natural vacancy, its components, and the causes of disequilibrium. We, therefore, can also develop a more coherent conceptual framework of real estate cycles in conjunction with supply constraints.
Search frictions inevitably derail competitive price formation in property markets and cause vacancy. This requires studies with the assumption of imperfect property markets, where clearance is not instantaneous and without cost. The search and matching theory is developed by Diamond (1971)[57] to explain unemployment in labour markets. Diamond's (1971)[57] paradox suggests that even small search costs drive equilibrium from a competitive to a monopoly price. Further, theoretical work by Diamond (1982)[58] features multiple steady-state rational expectations equilibriums implying that the economy with trade frictions - (Salop 1979)[151] - does not have a unique natural rate of unemployment due to search externalities generating inefficient outcomes at the macro level - i.e. time-varying features of natural unemployment exist. Since the concept of natural vacancy in property markets is similar to the one of natural unemployment in labour markets, we can expect time-varying characteristics for natural vacancy as well. Diamond's equilibrium model is rooted in the lifetime utility earned by an individual who switches from employment to unemployment. This has become the foundation of equilibrium models featuring search and matching, and further developments are presented by Mortensen and Pissarides (1985[138], 1994[131] and 1999[132]) who analysed how aggregate shocks lead to cyclical fluctuations in unemployment, job vacancy, and employment flow simultaneously. An aggregate matching function was set up to describe the search process between workers and firms. Whether a search process is sequential (i.e. an action taken in one period leads to several new actions becoming available in next period) or non-sequential depends on the searching methods, a search equilibrium does exist - Keller and Oldale (2003)[115], Van Ommeren and Russo (2014)[165]. The search equilibrium is reached when unemployment is maintained at the equilibrium state (i.e. natural rate of unemployment) and three components can be identified separately:

- **structural unemployment** is unemployment that results when wages are set above the level that brings supply and demand into equilibrium. The number of jobs available is insufficient to provide a job for everyone who wants one;

- **frictional unemployment** is due to the difficulty of matching workforce skills with requirements from demand. It takes time for workers to search for the jobs that best suit their tastes and skills;
- **cyclical unemployment** is related to short term fluctuations due to temporary phenomena (e.g. workforce mobility). It is the deviation of unemployment from its natural rate.

On one hand, the existing literature in real estate markets studies the creation of temporary inventories by landlords to maximize net rental receipts during periods of strong demand - Rosen et al. (1983), Shilling et al. (1987), Gabriel et al. (1988), Wheaton et al. (1988). In fact, landlords sometimes hold vacant space deliberately until they reach *ideal tenants* who can afford higher rents, i.e. with a *rental floor* above the equilibrium level (economic mismatch, even with a physical match). And, if we also consider the search process, deliberately holding vacant space may lead to an extension of the searching time. On the other hand, we could also observe vacant space because the physical characteristics of a building become obsolete for the new demand and hence a refurbishment becomes necessary to reach occupation. So far in the literature, these two features are not jointly studied and we believe it is insightful to combine them in a model to investigate how this behaviour determines equilibrium vacancy and market disequilibrium. In order to do so, we firstly identify three types of vacancy mirroring the labour market literature:

- **structural vacancy** derives from landlords holding empty buildings to wait for higher future rents which might be above equilibrium level (economic mismatch)
- **frictional vacancy** relates to the space on offer whose physical characteristics cannot be matched with tenants' requirements and hence this space is not absorbed until being refurbished (physical mismatch)
- **cyclical vacancy** refers to the excess property supply due to a short-term fluctuation in economic or business conditions (economic mismatch)

Importantly, the simultaneous effect of cyclical and structural/frictional factors on unemployment represents an obstacle to the empirical identification of each unemployment type - Rissman (1986)[146]. However, while cyclical factors lead to short-run unoccupied space, structural and frictional factors tend to affect the long-run equilibrium state; therefore, the estimation of an error correction model offers a suitable approach by separating the short-run impact from the long-run trend. In our model, short-term fluctuations will result from search disequilibrium and economic shocks.

Wheaton (1990)[175] extended the search and matching model from labour markets to housing markets and assumed structural vacancy being equivalent to natural vacancy computed as (1 - number of households/housing units) upon the condition that expected house prices equal marginal supply costs. Matching statuses vary by changes in households, which turn into new demand for larger or smaller houses, and the matching speed relies on the search effort required. To smooth the matching process, vacant houses are necessary in the long-run and structural vacancy can be explained by market activities. In our conceptual model, we jointly determine structural vacancy with a matching process. Building our conceptual model, we also empirically demonstrate the importance of search and matching to estimate supply elasticity.

3.4 Conceptual Framework

We set up the conceptual model to determine the relationship between natural vacancy and supply elasticity in commercial real estate rental markets following the previous work of Wheaton (1990)[175] in housing markets. We classify *mismatch* between landlords and tenants into two categories: economic and physical.

Economic mismatch is defined as the point at which desired rent levels (r^D) of a landlord cannot be satisfied. In other words, all bid rents offered by tenants (r^B) are lower than the landlord's asking rent.

For physical characteristics, instead, we distinguish property space S as defined by N heterogeneous characteristics (i.e. building facilities such as ventilators, lifts, car parks, panoramic views, size, etc.), with i referring to the element of the set ($I = 1, \cdots, N$). Tenants' required property characteristics j can be divided into two groups: (1) matched with space characteristics provided, and (2) partially unmatched characteristics. Some provided space characteristics may also be redundant and no tenant requires them. J denotes the set of tenants' required characteristics, and its major part is the overlapping subset with I.

Physical mismatch is identified by the second group of J and redundant space characteristics offered. Suppose some i match with j belonging to the first group of J. We denote i as i_m indicating with subscript m that characteristics are matched. Instead, bundles of characteristics i not matching j are defined as i_n, where subscript n stands for non-matched (i.e. mismatched) characteristics. If we consider the time-varying feature of property space in the long-run, the supply of space can be categorized as follow: $S_{i_m,l,t}$ and $S_{i_n,l,t}$, where t represents time.

Combining physical and economic matching, space supply is divided into four main groups:

- Both economic and physical match: $S_{i_m|r_t^B \geq r_t^D,l,t}$
- Economic mismatch and physical match: $S_{i_m|r_t^B < r_t^D,l,t}$
- Economic match and physical mismatch: $S_{i_n|r_t^B \geq r_t^D,l,t}$
- Both economic and physical mismatch: $S_{i_n|r_t^B < r_t^D,l,t}$

3.4.1 Vacancy Type

Vacancy (classified as mismatched space) depends on both economic and physical matching. If both economic and physical characteristics are matched, the space is occupied by tenants. At time 0 (i.e. when a rental contract is signed), all deals are made in the condition that both economic and physical requirements are satisfied. Long-term leases lead to changes in mismatch status of occupied space because of immediate rent adjustments by landlords and/or tenants moving to suitable office space based on their latest requirements. This short- vs long-run dynamic implies that the mismatch status of occupied space may switch among the four aforementioned groups, with a minor role played by the last group. On the other hand, new tenants may introduce new requirements of space characteristics and bid and/or asking rents may change as a consequence. Clearly, the status of vacant space may vary over time among the last three types (excl. joint economic and physical match). We further classify space supply according to its tenancy (occupied vs vacant) and the mismatch status (matched vs non-matched and economic vs physical) in the following equation:

$$
\begin{aligned}
S_{i,l,t} = {} & S_{i_m|r_t^B \geq r_t^D,l,t}(occupied) + S_{i_m|r_t^B < r_t^D,l,t}(occupied) + \\
& S_{i_n|r_t^B \geq r_t^D,l,t}(occupied) + S_{i_n|r_t^B < r_t^D,l,t}(occupied) + \\
& S_{i_m|r_t^B < r_t^D,l,t}(vacant) + S_{i_n|r_t^B \geq r_t^D,l,t}(vacant) + S_{i_n|r_t^B < r_t^D,l,t}(vacant)
\end{aligned}
\tag{3.1}
$$

When the search and matching process is completed, a long-run stable equilibrium is reached, where physically mismatched space would not be occupied any longer; [2] therefore, equation 3.1 collapses into equation 3.2 in the long-run:

[2]The second line of equation 3.1 - $S_{i_n|r_t^B \geq r_t^D,l,t}$(occupied) and $S_{i_n|r_t^B < r_t^D,l,t}$ (occupied) - equal zero because occupied and physically mismatched space either becomes vacant or refurbished and then matched in the long-run.

$$S_{i,l,t} = S_{i_m|r_t^B \geq r_t^D,l,t}(occupied) + S_{i_m|r_t^B < r_t^D,l,t}(occupied) + S_{i_m|r_t^B < r_t^D,l,t}(vacant) + S_{i_n,l,t}(vacant) \tag{3.2}$$

Following a three-way decomposition of the vacancy rate taken from the labour literature, we then identify the three types of vacancies as follows:

Structural vacancy: Landlords deliberately hold vacant space (maybe unlisted) until reaching out to their *ideal tenants* who can afford rents exceeding an equilibrium level, i.e. a *rent floor* is set above the equilibrium level. Assuming that the space characteristics match tenants' requirements but bid rents are lower than asking rents, structural vacancy ($V_{l,t}^s$) is a percentage rate of $S_{i_m|r_t^B < r_t^D,l,t}(vacant)/S_{i,l,t}$ that we classify as *economically mismatched and physically matched.*

Frictional vacancy: The process of matching physical characteristics of buildings may lead to the formation of a vacancy. A certain amount of space may not match tenants' requirements and therefore it may not be occupied until it is renovated. We qualify this type of vacant space as *physically mismatched*, and according to equation 3.2, frictional vacancy ($V_{l,t}^f$) is obtained as $S_{i_n,l,t}(vacant)/S_{i,l,t}$ [3].

Cyclical vacancy: Excess property supply results from short-term fluctuations in the general economy or the specific business sector that requires office space. However, responses of tenants and landlords to short-term shocks are delayed because of fixed-term leases and construction lags. This type of vacant space ($V_{l,t}^c$) is supposed to match with tenant's requirements, and we classify it as *economically mismatched and physically matched.*

To summarize, a natural vacancy rate ($V_{l,t}^n$) exists in the long-run, and the sum of structural and frictional vacancy represents its measure. Particularly, structural vacancy represents the non-cyclical component of $S_{i_m|r_t^B < r_t^D,l,t}(vacant)/S_{i,l,t}$.

3.4.2 Short Run and Long Run Supply Curve

Following Helsley and Strange (2008) [102], we construct the increasing and convex construction function with respect to building height and the concave profit function of a developer. To benefit from economies of scale, a developer decides

[3] The last term of equation 3.2 is obtained by adding the last two terms of equation 3.1 without distinguishing economic match vs mismatch for physically mismatched properties in the long-run.

how many floors should be built to maximize the profit. This convex construction function implies a convex kinked long-run supply curve:

$$\pi(h_{l,t}) = r_{l,t}h_{l,t} - c(h_{l,t}) \tag{3.3}$$

π: developer's profit

$h_{l,t}$: building height for a developed property which is located in city l at time t

$r_{l,t}$: rent per floor for a property in city l at time t

c: construction function.

When $r_{l,t} = c'(h_{l,t})$, the profit is maximized. New supply is assumed to match tenants' needs as developers thoroughly study tenants' demand and their preferences of property characteristics before building. In addition, we assume that developers also base their investment decision on expected rental growth, with demand shocks in property markets leading to changes in expectations about future rents. The short-run supply is extremely inelastic as weak responsiveness to rental changes is the result of construction lags.

3.4.3 Short- and Long-Run Equilibrium Rent

The demand function ($D_{l,t}$) of commercial properties is driven by factors linked to industry-related revenues and expectations about the future business environment. The income growth for residents may reflect the prosperity of the business environment, as more bonuses would be shared with employees in a robust economy. A demand shock is normally triggered by a business environment change such as a shock in employment for sectors requiring office space. At the same time, we assume that corporations can execute an immediate plan to adjust the workforce after anticipating the future business outlook. In other words, current employment ($EM_{l,t}$) in city l at time t indicates the expectation about the future business environment, which drives demand for space. Along with aggregate income for residents ($RI_{l,t}$) and rents ($r_{l,t}$), equation 3.4 describes the long-run demand.

$$D_{l,t} = f(EM_{l,t}, RI_{l,t}, r_{l,t}) \tag{3.4}$$

Figure 3.1 shows the effect of a positive shock to the aggregate demand (from $AD1$ to $AD2$) due to a sudden increase in employment caused by a company relocation to the city. Rents increase and, as a consequence, the amount of supply slightly increases; however, the growth is curtailed by an inelastic short-run supply.

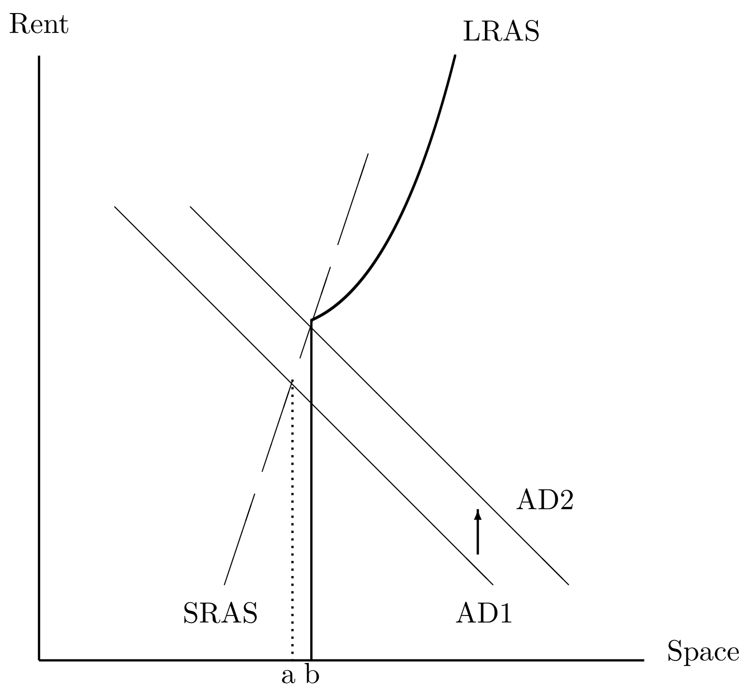


Figure 3.1: Long- and Short-Run Aggregate Demand and Supply Curve of Property Space

At the point of long-run equilibrium, the demand ($D_{l,t}$) for office space should exactly equal the amount of supply ($S_{l,t}$) after some adjustments. However, a small component of supply remains unoccupied because of market frictions (a costly search and matching process generates frictional vacancy ($V^f_{l,t}$) and the landlords' strategy of holding vacant space for future gains gives rise to structural vacancy ($V^s_{l,t}$). Therefore, we expect that in equilibrium demand equals supply only after deducting vacant space due to frictional and structural vacancy as follows:

$$D_{l,t} = (1 - V^f_{l,t})(1 - V^s_{l,t})S_{l,t} \tag{3.5}$$

In the short-run, changes in demand are not completely met by changes in supply. The *satisfaction*, quantified by space absorption, hinges on matching rates ($\omega_{l,t}$) of tenants in market l. As suggested in Cheshire et al. (2018)[38], a matching rate is determined by the level of search effort required ($\epsilon_{l,t}$) and the ratio of vacant property to mismatched tenants ($\theta_{l,t} = S_{l,t}$(vacant) / $S_{i_m|r^B_t<r^D_t,l,t}$(occupied))

through a constant return to scale Cobb-Douglas matching function (Cheshire et al. 2018):

$$\omega_{l,t} = \alpha * \epsilon_{l,t}^{\beta} * \theta_{l,t}^{(1-\beta)} \tag{3.6}$$

where α is a constant and β represents the weighting. Therefore, space absorption can be described by equation 3.7. If demand was fully met, the distance *"ab"* in the Figure 1 would indicate the net absorption in the short-run.

$$AB_{l,t} = \Delta D_{l,t} * \omega_{l,t} \tag{3.7}$$

Simultaneously, a construction lag hinders immediate supply responses and, as a result, changes in supply are not fully realized. In order to reflect an effect of construction lag in our empirical investigation, a lagged change in supply is singled out to determine a change in vacancy and z in equation 3.8 represents the number of construction lags.

$$\Delta V_{l,t} = \Delta S_{l,t-z} - \Delta D_{l,t} * \omega_{l,t} \tag{3.8}$$

Assuming that one unit of demand shock in the market stimulates a one percent increase in rents, equation 3.8 suggests that a change in vacancy can be estimated by subtracting the matching rate from the responsiveness of supply. A matching rate model is used to identify structural vacancy and, assuming negligible frictional vacancy rates, the change in vacancy can be decomposed into supply elasticity and change in structural vacancy.

3.5 Empirical Strategy

The systems of long- and short-run simultaneous equations are constructed based on the above conceptual framework to find empirical evidence for our arguments:

- the cyclicality of a commercial real estate market is determined by a search and matching process, which identifies structural vacancy;
- the search and matching process is necessary to estimate supply elasticity consistently.

3.5.1 Empirical Model

Our empirical model captures the mismatch between landlords and tenants and the search effort required to find the search equilibrium. First, we derive the equation of long-run real rent from the demand function (equation 3.4) and, subsequently, we add the mismatch variable, which proxies for the need of searching. Second, we assume that landlords are capable of controlling the matching process; therefore, the long-run supply equation contains both a mismatch rate and search effort level, which are determined by the quantity of information about available properties. Moreover, operating expenses charged by property management firms and the difference between capitalization and mortgage rates are considered cost shifters.

Third, because of a concern about endogeneity in the matching process, we introduce simultaneous equations for search effort level and mismatch rate. The equation of search effort level is constructed with real aggregate personal income (exogenous), which proxies for business outlook, and rents and supply as the two endogenous factors in the search process. A change in city size, which is identified by a change in population, alters the mismatch rate because new tenants may increase demand by moving in from other cities. Shifts in business outlook are also considered because the tenants' plan for expansion and the landlords' strategy to seek "targeted" tenants may be altered. Therefore, the equation of mismatch rate contains population and aggregate personal income as proxies for business outlook along with property supply.

As a whole, four long-run equations are built in a simultaneous system, where variables are transformed to natural logarithms (excl. mismatch rate, search effort level, and cap minus mortgage rates), and fixed time effects and fixed MSA effects are used to capture any unobserved time-varying or local characteristics. The residual of each long-run equation is represented by $\mu_{l,t}$, and its lagged term $\mu_{l,t-1}$ is the error correction term used in the short run equations to compute the speed of adjustment to reach a long-run equilibrium. The simultaneous system is solved using a three-stage least squares estimation.

Covering 43 MSAs, the system of long-run simultaneous equations can be represented as follows (please refer to Table 3.2 for notations):

$$ln(RRI_{l,t}) = d_0 + d_1 ln(S_{l,t-1}) + d_2 ln(EMP_{l,t-2} or INEMI_{l,t-2}) + d_3 ln(RIPC_{l,t-4}) + \\ d_4 MR_{l,t-1} + d_5 * Recession + d_6 ATH_t + \sum_{n=7}^{49} d_n MSA \times ln(S_{l,t-1}) + \mu_{l,t}^{RRI} \tag{3.9}$$

$$ln(S_{l,t}) = e_0 + e_1 ln(RRI_{l,t-12}) + e_2 ln(ROPEX_{l,t-12}) + e_3 SEL_{l,t-1} + e_4 MR_{l,t-1} + e_5 CM_{l,t-2} + e_6 * Recession + e_7 ATH_t + e_8 HU_l + e_9 ATH_t \times HU_l + e_{10} ATH_t \times ln(RRI_{l,t-12}) + e_{11} HU_l \times ln(RRI_{l,t-12}) + e_{12} ATH_t \times HU_l \times ln(RRI_{l,t-12}) + \sum_{m=13}^{55} e_m MSA \times ln(RRI_{l,t-12}) + \mu^S_{l,t} \tag{3.10}$$

$$MR_{l,t} = f_0 + f_1 ln(POPI_{l,t-1}) + f_2 ln(EMP_{l,t-1}) + f_3 ln(RIPC_{l,t-1}) + f_4 ln(S_{l,t-1}) + f_5 * Recession + \mu^{MR}_{l,t} \tag{3.11}$$

$$SEL_{l,t} = g_0 + g_1 ln(RRI_{l,t-1}) + g_2 ln(S_{l,t-1}) + g_3 ln(RIPC_{l,t}) + g_4 * Recession + \mu^{SEL}_{l,t} \tag{3.12}$$

Our aim is to estimate the long-run supply elasticity for each MSA. We compute it by adding coefficients e_1 to e_m of the corresponding MSA. In order to check the robustness of our model, we also compute demand elasticity by taking the reciprocal of the sum of d_1 and d_n of the corresponding MSA.
Construction costs are theoretically a significant determinant of property supply; however, we would need to restrict our analysis to only 30 MSAs if we were to include construction costs in our model because construction data is hardly available for all MSAs. Hence, we present the main results using the full sample of MSAs excluding construction costs and present an estimation of models including construction costs for the reduced sample as a robustness test. Results are not significantly different.

To capture short-run dynamics, we also solve four short-run simultaneous equations in an Engle-Granger framework. The reciprocal of the error correction term coefficient indicates the quarterly percentage of adjustment of each dependent variable (i.e. real rent, office stock, search effort level, and economic mismatch rate) to its long-run equilibrium. We expect coefficients to be negative and with an absolute value between 0 and 1.

$$\Delta ln(RRI_{l,t}) = d_{50} + d_{51}\Delta ln(S_{l,t-1}) + d_{52}\Delta ln(EMP_{l,t-2} or INEMI_{l,t-2}) + \\ d_{53}\Delta ln(RIPC_{l,t-4}) + d_{54}\Delta MR_{l,t-1} + d_{55}\mu^{RRI}_{l,t-1} + \nu^{RRI}_{l,t} \tag{3.13}$$

$$\Delta ln(S_{l,t}) = e_{56} + e_{57}\Delta ln(RRI_{l,t-12}) + e_{58}\Delta ln(ROPEX_{l,t-12}) + e_{59}\Delta SEL_{l,t-1} \\ e_{60}\Delta MR_{l,t-1} + e_{61}\Delta CM_{l,t-2} + e_{62}\mu^{S}_{l,t-1} + \nu^{S}_{l,t} \tag{3.14}$$

$$\Delta MR_{l,t} = f_6 + f_7\Delta ln(POPI_{l,t-1}) + f_8\Delta ln(EMP_{l,t-1}) + f_9\Delta ln(RIPC_{l,t-1}) + \\ f_{10}\Delta ln(S_{l,t-1}) + f_{11}\mu^{MR}_{l,t-1} + \nu^{MR}_{l,t} \tag{3.15}$$

$$\Delta SEL_{l,t} = g_5 + g_6\Delta ln(RRI_{l,t-1}) + g_7\Delta ln(S_{l,t-1}) + g_8\Delta ln(RIPC_{l,t}) + g_9\mu^{SEL}_{l,t-1} + \nu^{SEL}_{l,t} \tag{3.16}$$

Lag Selection

As the business outlook is normally projected based on actual performance over the previous year and corporations adjust their headcount over the following two quarters, an expansion of office space should be decided following a change in their work plan. We, therefore, choose a four-quarter lagged aggregate income per capita, two-quarter lagged employment to population, and one-quarter lagged office stock in our estimation. Furthermore, landlords may adjust asking prices based on recent evidence of economic mismatch and hence a rental adjustment may be realized upon a deal being agreed. As a result, a one-quarter lagged economic mismatch rate is selected.

As far as the supply equation is concerned, we rely on the findings of time-to-plan and time-to-build for non-residential buildings by Millar et al. (2012[129]) and Montgomery (1995[130]) and use a total time lag to plan and build 12 quarters for real rents, real construction costs, and real operating expenses. Although costs for funding should be considered in parallel with rents for appraisal purposes, we also need to consider the timing needed to release almost or just completed space based on foreseeable profitability, which can be proxied by the difference between a capitalization rate and costs of funding. If a good timing to catch high profitability is foreseen, the newly completed offices will be released to the market. Pre-let activities normally begin around two quarters before completion and this

time is then used as a lag for the difference between cap rates and mortgage rates. As credit markets mis-price risk (Wachter 2016[174]), the difference between cap rates and mortgage rates would be exogenous. Since supply in equilibrium is adjusted by structural vacancy, one-quarter lagged search effort level and mismatch rate are used to explain current supply.
As landlords can adjust the quantities of listed properties based on recent market developments and the current exogenous business environment, we expect the search effort level to be explained by one-quarter lagged real rent and office stock, as well as simultaneous real income per capita. Similarly, for the economic mismatch rate equation, one-quarter lagged office stock and current exogenous conditions of real income per capita and population index are selected. Real market rents are not included in this equation because landlords deliberately retain a certain amount of vacant space to seek opportunities of positive deviations from market rents.

Impact of Recession Period

We define recession as the period where real personal income per capita in MSA level declines. The most frequent recession period spans between 2008Q3 and 2009Q3 for almost all 43 MSAs. 2013Q1 is also defined as recession period for 43 MSAs.

Hurricane Effects

We limit our inclusion of hurricanes to the ones that originated in the Atlantic Ocean as others are much less intense and do not cause very significant damage in accordance with track records starting from 1851 (source: National Hurricane Center). To address hurricane effects in office supply, we include dummies of hurricane-threatened areas and occurrence of hurricanes from the Atlantic Ocean in equation 3.10. We separate the location (by MSA) and time dimension of hurricanes, but we also include interaction terms between the two dummies to capture the actual incidence in the supply equation. For the demand component, we only use the occurrence dummy to capture a temporary change in overall sentiment. Finally, we assume that the matching process is insulated from a temporary natural hazard effect and therefore no related dummies are added to the equations of economic mismatch and search effort level.

Lack of Transportation

Transportation infrastructure may be considered by developers/landlords in their supply function. We create a proxy for lack of transportation by using residents' travel time to work. We identify an area with lack of transportation when the travelling time is one standard deviation larger than the average. We capture this effect in the supply equation to conduct a robustness check on possible multicollinearity arising from the relatively high correlation (around +0.4) between the hurricane dummy and lack of transportation. Our results are not significantly affected.

Likelihood of Change in Frictional Vacancy
Alongside our main model, which currently estimates structural vacancy assuming a negligible impact of frictional vacancy, we also construct another set of simultaneous equations adding the likelihood of change in frictional vacancy. We assume that physical mismatch is found in non-prime offices only when a major refurbishment is required to make the space characteristics meeting demand requirements. Landlords can either look for more financially viable tenants to rent the existing non-prime quality space or upgrade the building to prime quality to earn higher rents and extend the economic life in the long-run. We assume that switching between physical and economic mismatch would occur at the "right" timing of refurbishment, which is one to two years long. We expect that the timing of refurbishment (and hence the likelihood of change in frictional vacancy) depends on the rental gap between prime and nonprime offices. We compile a set of six dummy variables with value 1 when the gross asking rent for prime offices is 10-60% higher than the one for non-prime offices. In our model, we add an interaction term between the four-quarter, or six-quarter or eight-quarter lagged dummy and current mismatch rate to proxy for the likelihood of physical mismatch turning into economic mismatch after refurbishment. A drawback of this approach is the need to use the current (rather than one-quarter lagged) economic mismatch rate to mitigate for the confusion of the lagged impact. Furthermore, the equation of mismatch rate also includes these dummies.

3.5.2 Dataset and Data Sources

We collect raw property data with a quarterly frequency from CBRE Econometric Advisors (CBRE EA hereafter), formerly Torto Wheaton Research. CBRE EA is an independent research firm owned by CBRE, which is one of the largest property consultancy firms in the US. They provide a comprehensive property market database to real estate investors. The database covers fundamental market and investment data at MSA level by property sectors, which include apartments (61

MSAs), offices (63), retail (63) and industrial (52) properties. Basic data such as rent, stock, vacancy, completion, net absorption and capitalization rate are provided in every property sector over time. Despite a possible discontinuity in time series for some MSAs, the office sector database is the most comprehensive in terms of time span (starting from the second quarter 1988) and greater depth of market data compiled by CBRE EA with information provided by property owners (e.g. availability rate, available but occupied space, total return, gross income and net operating income). Mortgage rates are obtained from the Federal Reserve, hurricane information from the National Hurricane Center and structure cost data from the Lincoln Institute of Land Policy. Other demographic and economic data on population, aggregate personal income, and employment base in the office sector are estimated by Moody's Analytics (formerly economy.com)[4] and obtained through the CBRE EA database.

To estimate the long-run supply elasticity of office markets using the mismatch model, we capture mismatch situations that are identified by available (i.e. listed for rental) but occupied space. Due to data availability starting only from the first quarter of 2005 for 43 MSAs (i.e. 47% of US population), a balanced panel dataset (dataset43) from the first quarter of 2005 to the fourth quarter of 2015 is used for this study. Construction cost data is also available and collected in 30 MSAs for the same period and they are included in the dataset used in the robustness test section (dataset30). Our main results are based on 43 MSAs and do not include construction costs. However, we still report the main descriptive statistics of both datasets in Table 3.2 showing the similarity of aggregate measures. A full set of estimation results including construction costs obtained with dataset30 is also reported in the Appendix. We also prepare longer time series data starting from the first quarter 1998 to the fourth quarter of 2015 except for the data of "available but occupied stock", which are unavailable before 2005 for robustness check.

If we exclude dummies, ten main variables are used in our model: four endogenous [real rent index ($RRI_{l,t}$), office stock ($S_{l,t}$), mismatch rate ($MR_{l,t}$) and search effort level ($SEL_{l,t}$)] and six exogenous [real construction structure cost index ($RSI_{l,t}$)[5], real operating expense ($ROPEX_{l,t}$), real personal income per capita ($RIPC_{l,t}$), difference between capitalization and mortgage rates ($CM_{l,t}$), ratio of employment in the office using sectors to population ($EMP_{l,t}$) and population index ($POPI_{l,t}$)]. These variables are obtained as follows:

[4] Economy.com has been the subsidiary of Moody's Analytics since 2005. They provide data and analysis on regional economies by country. Particularly in the US, labour markets, demographics, industries and other variables are offered at MSA level.

[5] It is used for panel B only.

Real Rent Index ($RRI_{l,t}$). A nominal rent index is taken from CBRE EA, which uses a hedonic modelling approach based on over 200,000 office leases on the basis of the non-discounted sum of all rental payments considering free rent periods but excluding tax. We deflate the nominal rent index using the Consumer Price Index (CPI) at the MSA level obtained from the Bureau of Labour Statistics.

Mismatch Rate ($MR_{l,t}$). We identify **economic mismatch** using the "available but occupied stock", which indicates office space listed by landlords while it is still occupied. This variable suggests that the existing tenant is not prepared to pay the asking rent at renewal and there is no incentive for a major refurbishment to be carried out after the existing tenant moves out. If the landlord is intending to carry out a refurbishment (suggesting the presence of a physical mismatch), the property would not be listed and made available for rental to new tenants. In our main model, the percentage of "available but occupied stock" is computed as the economic mismatch rate. As a robustness check, we also follow Cheshire et al. (2018)[38] and compute this rate as the ratio between "available but occupied stock" and vacant stock. This ratio indicates the extent to which the economic mismatch can be accommodated by the currently vacant stock.

Search Effort Level ($SEL_{l,t}$). Non-transparent information may hinder the search and matching process: the less the information provided by landlords, the greater is the effort for tenants to search for the matching. Hence, we quantify the search effort level by using the ratio between the following measures:

- the difference between the maximum number of buildings with asking rents in any quarter of the previous five years and the number of buildings with asking rents within the quarter, and
- the difference between the maximum and the minimum number of buildings with asking rents in any quarter of the previous five years.

Real Construction Structure Cost Index ($RSI_{l,t}$). Construction costs of offices are estimated by multiplying ratios of structure cost to house prices with office values. We deflate estimated costs with the CPI at the MSA level. This estimation might be affected by the difference of price growth between offices and housing.

Real Operating Expense ($ROPEX_{l,t}$). Nominal operating expenses are yielded by subtracting net operating income and tax from gross income. We deflate the nominal value by using the CPI at the MSA level.

Real Personal Income Per Capita ($RIPC_{l,t}$). We deflate aggregate personal income earned by residents with the CPI at the MSA level and divide it by population.

Cap Rate minus Mortgage Rate ($CM_{l,t}$). Capitalization rates exceeding the cost of funding signal the right timing for marketing nearly completed developments. Thus, we assume the existence of a positive relationship with office supply. As previously mentioned, this variable can be considered exogenous because of credit markets' mis-price risk as shown in Wachter (2016)[174].

Employment to Population ($EMP_{l,t}$). The employment base refers to the number of employees for financial and professional service industries. We compile the ratio of employment in these industries to population in MSA level.

In addition, we construct five dummy variables to capture the effect of recession, hurricane threat, lack of transportation for robustness check, and the likelihood of changes in frictional vacancy.

Recession Period. We define recession as the period where real personal income per capita declines as mentioned above.

Hurricane Threatened Area (HU_l): Tropical cyclones are cast from the Atlantic or East Pacific Ocean. Because most powerful hurricanes originate in the former, we define the threatened MSAs (including neighbouring areas) as the ones where at least one hurricane occurred within our sample period. According to the records from the National Hurricane Center, Baltimore, Cincinnati, Columbus, Fort Lauderdale, Houston, Indianapolis, Miami, Raleigh, Tampa, Trenton, West Palm Beach and Wilmington are selected among the MSAs we identify as HU.

Atlantic Hurricane Occurrence (ATH_t): To compile this dummy, we track the dates of hurricane occurrences (value of 1 if it occurs and 0 otherwise). The purpose of separating time and location dummies is to address both overall natural hazard risk and actual incidence.

Travel Time To Work ($TTWD_l$): If residents in certain cities spend more than one standard deviation above the MSAs average time to commute to work, the transportation infrastructure is regarded as insufficient.

Asking Rent Gap Between Prime and Non-prime Offices: Physically mismatched offices require a major refurbishment to avoid holding vacant space for long time periods. We assume this situation is limited to non-prime offices. Along with an extension to the economic life of a building, a major refurbishment also raises rents back to levels asked for prime quality buildings. Therefore, a gross asking rent gap between prime and non-prime offices can be used as a proxy for the likelihood of exercising a refurbishment option. After refurbishment, the previous physical mismatch (i.e. frictional vacancy) turns into an economic match (if space is occupied) or mismatch (if still vacant). The gap between prime and secondary rents can signal the likelihood of changes in a physical mismatch (the higher the gap the higher the incentive to refurbish), but it does not directly identify the amount of physical mismatch or frictional vacancy. We create six dummy variables where the asking rent gap is 10%, 20%, 30%, 40%, 50% and 60% to find out which level of the gap generates the greatest the likelihood of change in frictional vacancy.

Data statistics are summarized in Table 3.2. In general, there are no obvious outlier problems in the dataset.

Finally, to investigate the relationship between structural vacancy and supply elasticity, we use the components of our estimated long-run supply equation to estimate structural vacancy as a combination of economic mismatch rate and search effort level, dividing the exponential of $[e_3SEL_{l,t-1} + e_4MR_{l,t-1}]$ by total supply (please refer to Equation 3.10).

Table 3.2: Data Summary Statistics

		Dataset43						Dataset30	
Acronym	**Variable**	**Mean**	**S.D.**	**Min.**	**Max.**	**Skewness**	**Kurtosis**	**Mean**	**S.D.**
$RRI_{l,t}$	Real Rent Index (2015Q4=100)	101.310	13.205	58.343	158.271	0.447	4.705	98.893	11.788
$S_{l,t}$	Office Stock (million sqf)	78.823	85.651	4.799	491.340	2.867	12.515	99.398	94.768
$SEL_{l,t}$	$^{(a)}$ Search Effort Level	0.365	0.374	0	1	0.624	1.812	0.361	0.376
$MR_{l,t}$	$^{(b)}$ Economic Mismatch Rate (%)	4.668	1.719	0.739	12.274	0.228	3.229	4.569	1.579
$ROPEX_{l,t}$	$^{(c)*}$ Real Operating Expense (2015Q4p:USDmn)	161.045	70.993	7.258	504.062	2.168	10.860	162.057	75.335
$RIPC_{l,t}$	$^{(d)*}$ Real Personal Income Per Capita (USDth)	51.670	10.722	36.757	94.273	1.655	6.100	50.397	9.710
$CM_{l,t}$	$^{(e)*}$ Capitalization Minus Mortgage Rate (%)	1.163	1.270	-2.157	4.527	-0.216	2.385	1.200	1.303
$POPI_{l,t}$	* Population Index (2015Q4=100)	94.484	5.123	70.924	102.410	-1.136	4.207	94.657	4.875
$EMP_{l,t}$	* Employment in Office Using Sectors to Population	0.107	0.023	0.062	0.212	0.926	4.660	0.107	0.023
$EMI_{l,t}$	* Corresponding Employment Index (2015Q4=100)	92.210	7.306	63.855	108.200	-0.997	4.170	91.660	6.813
$INEMI_{l,t}$	* Information Industry Employment (2015Q4=100)	103.846	21.643	45.542	265.714	2.941	20.867	104.940	23.805
$RSI_{l,t}$	$^{(f)*}$Real Structure Cost Index (2015Q4=100)							89.797	21.281
HU_l	* Hurricane Threatened Area	0.209	0.407	0	1	1.429	3.042	0.233	0.423
ATH_t	* Atlantic Ocean Hurricane Occurrence	0.523	0.500	0	1	-0.091	1.008	0.523	0.500
$TTWD_l$	* Dummy for Travel Time to Work	0.14	0.347	0	1	2.081	5.329	0.133	0.340
$GRG50_{l,t}$	$^{(g)}$ Asking Rent Gap $\geq$ 40% (Prime vs Non-Prime)	0.077	0.266	0	1	3.183	11.131	0.089	0.284
$SV_{l,t}$	Estimated Structural Vacancy Rate (%)	2.663	2.883	0.200	20.471	3.501	17.660	1.668	0.980

Notes: All statistics are based on a sample of 1892 panel observations (44 quarters by 43 MSAs) for each variable (except RSI). (a) Search effort level is calculated as difference between maximum number of buildings in which asking rents are reported to CBRE over last 5 years and current number of reports divided by difference between maximum and minimum number of reports over last 5 years. (b) This indicates preference of landlords to letting the property to new tenants instead of existing tenants and is identified by rate of available but occupied stock. We define this situation as "economic mismatch" since by intuition landlords search for new tenants only when existing rent paid by current tenants is lower than their desired level. (c) Before deflating with consumer price index (CPI), operating expenses are estimated by subtracting net operating income and tax from gross income. (d) Aggregate personal income earned by residents are deflated with CPI. Real personal income is divided by population to compute income per capita. (e) This identifies that investment opportunities with leverage in office sectors are suitable to market. Positive gap implies that capitalization rate is greater than cost of fund. (f) We obtain the ratios of residential structure costs to house prices for 30 MSAs and estimate real construction costs of office buildings by multiplying these ratios with office values. However, we notice that difference in growth of prices between housing and offices may misestimate construction costs of office buildings. (g) The rent gap is the main criteria for landlords who own non-prime offices exercising refurbishment options in addition of refurbishment costs. If prime rents far exceed non-prime rents, landlords are motivated to renovate physical mismatched property and hence reduce leading frictional vacancy. This condition is captured into the model in order to mitigate distortion of structural vacancy by change in frictional vacancy, however cannot be used for identifying frictional vacancy that is unlike structural vacancy which can be identified by search and matching adjusted stock. * indicates exogenous variables (all others are endogenous).

3.5.3 Multicollinearity

In order to eliminate multicollinearity issue, we compile real personal income per capita, ratio of employment to population and population index. The correlation matrix shows low correlation among nine variables.

Table 3.3: Correlation Matrix

	$\ln(RRI_{l,t})$	$\ln(S_{l,t})$	$SEL_{l,t}$	$MR_{l,t}$	$\ln(ROPEX_{l,t})$	$\ln(RIPC_{l,t})$	$CM_{l,t}$	$\ln(POPI_{l,t})$	$\ln(EMP_{l,t})$
$\ln(RRI_{l,t})$	1								
$\ln(S_{l,t})$	-0.351***	1							
$SEL_{l,t}$	-0.267***	0.059**	1						
$MR_{l,t}$	-0.275***	0.173***	0.123***	1					
$\ln(ROPEX_{l,t})$	0.022	0.266***	0.101***	0.087***	1				
$\ln(RIPC_{l,t})$	-0.153***	0.188***	0.137***	0.250***	0.468***	1			
$CM_{l,t}$	-0.341***	-0.046**	0.063***	0.444***	-0.268***	-0.202***	1		
$\ln(POPI_{l,t})$	-0.043*	0.094***	0.327***	0.399***	0.151***	0.153***	0.334***	1	
$\ln(EMP_{l,t})$	-0.045**	0.238***	0.126***	0.047**	0.204***	0.363***	-0.246***	-0.024	1

Note: In order to mitigate multicollinearity concern, we compile population index ($POPI_{l,t}$), ratio of office using employment to population ($EMP_{l,t}$) and real personal income per capita ($RIPC_{l,t}$). Correlation coefficients among nine variables remain at low level. That means multicollinearity problem is solved by compiling index or ratios variables. $RRI_{l,t}$, $S_{l,t}$, $SEL_{l,t}$, $MR_{l,t}$, $ROPEX_{l,t}$ and $CM_{l,t}$ mean real rent index, office supply, search effort level, economic mismatch rate, real operating expense and capitalization minus mortgage rates. (*:p<0.1; **:p<0.05; ***:p<0.01)

3.5.4 Panel Unit Root and Cointegration Tests

To confirm the existence of short-run dynamics, we conduct panel unit root and cointegration tests. Because of heterogeneous characteristics of property markets across MSAs, we select the Im-Pearson-Shin (IPS hereafter) panel unit root test and the Pedroni panel cointegration test, where we assume heterogeneous intercepts and trends. The IPS panel unit root test results confirm that all variables (except real construction cost index) are integrated of order one - i.e. I(1) - as the residual series of the nine variables in their level and first differences are respectively non-stationary and stationary at 1% significant level[6]. In particular, since stock is accumulated and demolition rarely occurs, we assume that its non-stationarity is characterized as a deterministic trend process and hence a deterministic non-stationarity of $\ln(S_{l,t})$ is tested. We also prove that $\ln(S_{l,t})$ is an I(1) time series[7].

Since all variables satisfy the requirements of cointegration, we also conduct the residual-based Pedroni panel cointegration test for the four equations in our system and use seven statistics including four within-dimension-based (i.e. panel-ν, panel-ρ, semi-parametric panel-t (PP) and parametric panel-t (ADF)), and three between-dimension-based (i.e. group-ρ, semi-parametric group-t (PP) and parametric group-t (ADF)). Among all statistics, panel-ν and parametric group-t (ADF) have the highest and lowest power respectively[8]. The within-dimension based statistics are computed using estimators that pool the autoregressive coefficient across different MSAs for the unit root tests on the estimated residuals. In contrast, the between-dimension based statistics rely on estimators that average individually estimated coefficients for each MSA. All four equations show the rejection of the null hypothesis of "no cointegration" (with the only exception of panel- and group-ρ) and therefore we can confirm the need to use an Engle-Granger based error correction model assuming a cointegration in the long-run and a short-run adjustment[9].

Our aim is to examine the importance of search and matching theory by comparing the main models with others where either or both variables $SEL_{l,t}$ and $MR_{l,t}$ are dropped. However, in our empirical exercise, we could drop either $SEL_{l,t}$ or $MR_{l,t}$ simultaneously maintaining a cointegrated relationship in office stock to validate the error correction model; therefore, we build an alternative

[6]The capture of I(0) variable would not affect cointegration among I(1) variables, therefore we still include construction costs in our robustness tests with 30 MSAs

[7]Please refer to Table 3.4 for a full set of results.

[8]It refers to a proportion of times that the null hypothesis (i.e. no cointegration) is rejected when some or all time series in the panel are cointegrated.

[9]Please refer to Table 3.5 for a full set of these statistics.

simultaneous system without required search effort or economic mismatch rate for the robustness check. In addition, our conclusion of cointegration is also supported by most test statistics being significant. To exercise the strictest rule, we also construct first difference models to analyse long-run relationships for the robustness check and further comparison.

Table 3.4: Im-Pearson-Shin Panel Unit Root Test Results

Variable	**Im-Pearson-Shin W Statistic**		**I(1) (Y/N)**		
	Level	**First Difference**	**1%**	**5%**	**10%**
Dataset43: 43 MSAs					
Ln(Real Rent Index) [ln($RRI_{l,t}$)]	0.749	-22.862***	Y	Y	Y
[(a)]Ln(Stock) [ln($S_{l,t}$)]	2.221	-19.667***	Y	Y	Y
+Mismatch rate [$MR_{l,t}$]	0.073	-38.662***	Y	Y	Y
+Search Effort Level [$SEL_{l,t}$]	3.752	-29.311***	Y	Y	Y
Ln(Real Operating Expense) [ln($ROPEX_{l,t}$)]	-1.141	-27.032***	Y	Y	Y
Ln(Real Personal Income Per Capita) [ln($RIPC_{l,t}$)]	3.282	-41.212***	Y	Y	Y
+(Cap - Mortgage Rate) [$CM_{l,t}$]	-0.061	-18.867***	Y	Y	Y
Ln(Employment to Population) [ln($EMP_{l,t}$)]	4.217	-11.253***	Y	Y	Y
Ln(Population Index) [ln($POPI_{l,t}$)]	7.992	-13.224***	Y	Y	Y
Dataset30: 30 MSAs					
Ln(Real Rent Index) [ln($RRI_{l,t}$)]	0.493	-19.736***	Y	Y	Y
[(a)]Ln(Stock) [ln($S_{l,t}$)]	3.744	-17.997***	Y	Y	Y
+Mismatch rate [$MR_{l,t}$]	0.450	-31.780***	Y	Y	Y
+Search Effort Level [$SEL_{l,t}$]	3.530	-24.233***	Y	Y	Y
Ln(Real Structure Cost Index) [ln($RSI_{l,t}$)]	-2.841***	-11.574***		I(0)	
Ln(Real Operating Expense) [ln($ROPEX_{l,t}$)]	-1.068	-21.510***	Y	Y	Y
Ln(Real Personal Income Per Capita) [ln($RIPC_{l,t}$)]	4.174	-34.550***	Y	Y	Y
+(Cap - Mortgage Rate) [$CM_{l,t}$]	-0.468	-8.487***	Y	Y	Y
Ln(Employment to Population) [ln($EMP_{l,t}$)]	2.522	-8.448***	Y	Y	Y
Ln(Employment Index of Information Industry)[ln($INEMI_{l,t}$)]	3.157	-18.188***	Y	Y	Y
Ln(Population Index) [ln($POPI_{l,t}$)]	5.617	-11.949***	Y	Y	Y

Notes: (a) Individual intercept and trend are assumed since the series are non-stationary along trend. Other series assume individual intercept only in the panel unit root test. + Natural logarithm is not taken and original rates (%) are used as input in the model since the series contain zero value. Other variables are transformed in the form of natural logarithm. Signs ***, ** and * represent significant level at 1%, 5% and 10% respectively.

Table 3.5: Panel Cointegration: Pedroni Test Results

Variables	Panel Statistics				Group Statistics			Cointegrated
	V	Rho	PP	ADF	Rho	PP	ADF	(Y/N)
Dataset43:								
RRI equation:								
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($EMP_{l,t}$), ln($RIPC_{l,t}$) and $MR_{l,t}$	5.617***	0.040	-4.507***	-5.371***	1.077	-5.770***	-6.319***	Y
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($EMP_{l,t}$) and ln($RIPC_{l,t}$)	4.339***	0.196	-2.749***	-2.157**	0.998	-3.413***	-2.993***	Y
S equation:								
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($ROPEX_{l,t}$), $SEL_{l,t}$, $MR_{l,t}$ and $CM_{l,t}$	2.157**	1.868	-2.521***	-3.215***	3.803	-2.665***	-3.151***	Y
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($ROPEX_{l,t}$), $MR_{l,t}$ and $CM_{l,t}$	2.598***	1.411	-1.833**	-1.574*	3.124	-1.406*	-1.026	Y
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($ROPEX_{l,t}$), $SEL_{l,t}$ and $CM_{l,t}$	2.579***	1.223	-2.043**	-2.523***	2.948	-1.963**	-2.469***	Y
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($ROPEX_{l,t}$) and $CM_{l,t}$	7.629***	3.758	0.930	-0.500	5.026	1.409	-0.552	N
SEL equation:								
(No) $SEL_{l,t}$, ln($RRI_{l,t}$), ln($S_{l,t}$) and ln($RIPC_{l,t}$)	2.494*	-0.600	-1.858*	-2.213**	1.740	-0.485	-1.362*	Y
MR equation:								
(No) $MR_{l,t}$, ln($POPI_{l,t}$), ln($EMP_{l,t}$), ln($RIPC_{l,t}$) and ln($S_{l,t}$)	5.457***	-0.558	-3.078***	-2.996***	0.312	-3.494***	-3.585***	Y
Dataset30:								
RRI equation:								
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($EMP_{l,t}$), ln($RIPC_{l,t}$) and $MR_{l,t}$	1.759**	-2.951***	-7.196***	-6.895***	-1.501*	-6.934***	-6.616***	Y
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($EMP_{l,t}$) and ln($RIPC_{l,t}$)	2.830***	-4.710***	-8.020***	-7.230***	-3.092***	-7.615***	-6.817***	Y
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($INEMI_{l,t}$), ln($RIPC_{l,t}$) and $MR_{l,t}$	5.006***	0.216	-2.741***	-3.892***	1.872	-2.294**	-3.397***	Y
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($INEMI_{l,t}$) and ln($RIPC_{l,t}$)	5.514***	-0.896#	-3.297***	-3.759***	0.618	-3.250***	-4.107***	Y
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($INEMI_{l,t}$), ln($RIPC_{l,t}$), ln($POPI_{l,t}$) and $MR_{l,t}$	1.755**	-0.080	-4.434***	-4.055***	1.312	-4.367***	-3.539***	Y
(Trend) ln($RRI_{l,t}$), ln($S_{l,t}$), ln($INEMI_{l,t}$), ln($RIPC_{l,t}$) and ln($POPI_{l,t}$)	2.260**	-0.889#	-4.182***	-4.302***	0.669	-3.98***	-4.098***	Y
S equation:								
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($RSI_{l,t}$), ln($ROPEX_{l,t}$), $SEL_{l,t}$, $MR_{l,t}$ and $CM_{l,t}$	1.368*	3.632	-1.442*	-3.748***	5.382	-1.113	-4.281***	Y
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($RSI_{l,t}$), ln($ROPEX_{l,t}$), $MR_{l,t}$ and $CM_{l,t}$	0.305	1.393	-2.803***	-4.103***	3.489	-2.527***	-2.929***	Y
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($RSI_{l,t}$), ln($ROPEX_{l,t}$), $SEL_{l,t}$ and $CM_{l,t}$	14.686***	2.751	-0.671	-1.344*	4.204	-0.619	-1.922**	N
(Trend) ln($S_{l,t}$), ln($RRI_{l,t}$), ln($RSI_{l,t}$), ln($ROPEX_{l,t}$) and $CM_{l,t}$	8.308***	3.650	1.054	0.829	5.056	1.902	0.965	N
SEL equation:								
(No) $SEL_{l,t}$, ln($RRI_{l,t}$), ln($S_{l,t}$) and ln($RIPC_{l,t}$)	2.306*	-0.873	-1.950*	-2.828**	1.189	-0.666	-1.912**	Y
(Trend) $SEL_{l,t}$, ln($RRI_{l,t}$), ln($S_{l,t}$) and ln($RIPC_{l,t}$)	2.671**	-0.277	-2.388**	-4.156***	1.536	-1.455*	-3.701***	Y
MR equation:								
(No) $MR_{l,t}$, ln($POPI_{l,t}$), ln($EMP_{l,t}$), ln($RIPC_{l,t}$) and ln($S_{l,t}$)	1.271	-1.173	-3.722***	-4.855***	0.508	-3.548***	-4.637***	Y
(Trend) $MR_{l,t}$, ln($POPI_{l,t}$), ln($EMP_{l,t}$), ln($RIPC_{l,t}$) and ln($S_{l,t}$)	-0.892	0.372	-3.592***	-5.105***	2.044	-4.346***	-4.031***	Y

Notes: We assume deterministic trend in long run state of RRI and S based on the straightforward law of demand and supply. However, mismatch is caused by landlords' strategy for seeking exceedingly rent opportunities which strongly positively deviate from market level. Furthermore, information released by landlords may not have heterogeneous trend. Thus, we do not assume deterministic trend in MR and SEL for Dataset43. Signs ***, **, and * represent significant level at 1%, 5%, and 10% respectively.

3.6 Estimation Results

We initially present the estimation results of long-run relationships and subsequently report the speed of adjustment for short-run dynamics. A full set of results for short-run relationships is available in the Appendix.

3.6.1 Long-Run Relationships

We construct six versions of our simultaneous system. To be consistent with our findings on heterogeneous trends across MSAs in panel unit root and cointegration tests, all versions include an interaction term between MSA dummies and supply ($MSA \times ln(S_{l,t-1})$) in the rent equation and between MSA dummies and real rents ($MSA \times ln(RRI_{l,t-12})$) in the supply equation. Since property market dynamics are usually localized due to supply constraints, this assumption is also in line with our objective function. Models M1 to M4 differ for the inclusion of the aforementioned interaction terms between MSAs and lagged rent and supply in:

- equations of rent and supply only (M1);
- equations of rent, supply and economic mismatch rate (M2);
- equations of rent, supply and search effort level (M3);
- all four equations (M4).

Model M5 uses three equations only excluding search effort level and model M6 uses three equations only excluding the economic mismatch rate equation to test their significance in our system.

Real Rent

Table 3.6a exhibits the long-run relationship of real rents derived from the demand function, where we find that supply, demand factors, and mismatch rate are significant to set real rents, with supply being the dominant factor: a 1% increase in supply, mismatch rate, and real personal income per capita or employment to population respectively lead to a reduction of 1.9-2% and 0.02-0.7%, and an increase of 0.57% and 0.62-0.64%. The coefficient on recession period is consistently negative across models, confirming the belief that the GFC has brought a bust in office markets. Furthermore, the occurrence of hurricanes originated in the Atlantic Ocean increases real rents (probably through a reduction in supply). Overall, statistically insignificant coefficients for the interaction terms in the economic mismatch equation in models M2 and M4 and the lowest Bayesian Information Criteria among models M1 to M4 suggest that model M1 is the preferred choice. Finally, distortion driven by interaction terms in the economic mismatch equation may occur in other systems. Similar circumstances are found when adding interaction terms with MSAs to model M3, but changes are a bit more vigorous. These may imply that the search and matching process does not have strong local factors. Comparing M1 with M5 (excluding search effort level), results seem to suggest that determinants of real rents do not have significant changes. Similar conclusion is drawn when comparing M1 with M6 (excluding economic mismatch rate).

Table 3.6a: Panel A: Long Run Relationship of Real Rent ($\ln(RRI_{l,t})$)

Independent Variable	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
Constant	9.288***	9.704***	9.161***	9.572***	9.182***	9.704***
	(2.441)	(2.443)	(2.442)	(2.444)	(2.443)	(2.441)
ln($S_{l,t-1}$)[a]	-2.007	-1.861	-2.033	-1.867	-2.064	-1.968
ln($EMP_{l,t-2}$)	0.633***	0.624***	0.635***	0.627***	0.636***	0.637***
	(0.052)	(0.052)	(0.052)	(0.007)	(0.052)	(0.052)
ln($RIPC_{l,t-4}$)	0.574***	0.565***	0.574***	0.566***	0.575***	0.57***
	(0.067)	(0.066)	(0.067)	(0.067)	(0.067)	(0.066)
$MR_{l,t-1}$	-0.0003	-0.0002	-0.007***	-0.002	-0.0002	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	
Recession Period	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
ATH	0.009***	0.009***	0.008***	0.010***	0.009***	0.009***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Fixed MSA Effect	Y	Y	Y	Y	Y	Y
F-Stat	76.73	76.79	76.71	76.77	76.71	77.59
BIC - Simultaneous System	-8200	-8171	-8183	-8149	-7951	-12289
R-sq	0.83	0.83	0.83	0.83	0.83	0.83
Observation	1376	1376	1376	1376	1376	1376

Notes: (a) Median values. We build the simultaneous system which consists of four equations. We report the results of first equation in this table. Real rent index ($\ln(RRI_{l,t})$) is the dependent variable. Supply ($\ln(S_{l,t-1})$), employment in office using sectors to population ($\ln(EMP_{l,t-2})$), real personal income per capita ($\ln(RIPC_{l,t-4})$), economic mismatch rate ($MR_{l,t-1}$), recession period dummy and Atlantic Ocean Hurricane Occurrence dummy (ATH) as well as interaction terms of MSA with lagged supply are independent variables. Signs ***, **, * represent significant level at 1%, 5%, 10% respectively.

Office Stock

Table 3.6b summarizes the long-run relationship of office supply. According to the first four models, a 1% increase in real rents leads to an increase in supply by 0.11-0.13%, while real operating expenses do not seem to influence supply economically (-0.01%). Relatively to real rents, the impact of the economic mismatch rate is similar (-0.1%), while a very small economic impact of search effort level is found. We use the lagged difference between cap and mortgage rates to proxy for pre-let activities (to indirectly enhance the accuracy in measuring vacancy adjustments), which exert a minimal impact on overall supply (+0.01%).

Focusing on the hurricane effect, we use a three-way interaction term to estimate differential impacts and find some discrepancies in results among models. We mainly discuss results in M1 as it represents the model with the best fit (see discussion above). For MSAs bearing hurricane risk, supply is about 2% smaller than for others without hurricane risk, however this estimation is statistically insignificant. Whether we ignore or consider the occurrence of hurricanes, a 1% increase in real rents in an area facing hurricane risk would lead to a 0.23% decrease in supply. Coupling with insignificant impacts of interactions between changes in real rent and hurricane occurrence, this implies that a long-term hurricane risk, not only its occurrence, may moderately affect developers and landlords' decisions.

Table 3.6b: Panel B: Long Run Relationship of Office Supply ($\ln(S_{l,t})$)

Independent Variable	M1	M2	M3	M4	M5	M6
Constant	4.211***	4.207***	4.226***	4.223***	4.167***	4.216***
	(0.118)	(0.118)	(0.118)	(0.118)	(0.119)	(0.118)
ln($RRI_{l,t-12}$)[a]	0.126	0.127	0.121	0.113	0.132	0.129
ln($ROPEX_{l,t-12}$)	-0.007***	-0.007***	-0.007***	-0.007***	-0.007***	-0.007***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$SEL_{l,t-1}$	-0.011***	-0.011***	-0.010***	-0.010***		-0.011***
	(0.002)	(0.002)	(0.002)	(0.002)		(0.002)
$MR_{l,t-1}$	-0.001***	-0.001***	-0.001***	-0.001***	-0.001**	
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	
$CM_{l,t-2}$	0.013***	0.013***	0.013***	0.013***	0.013***	0.013***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Recession Period	0.0005	0.0005	0.0005	0.0005	0.0005	0.0004
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ATH					0.027	
					(0.021)	
HU_l	-0.019	-1.627***	-0.001	0.002	-1.516***	-0.060
	(0.205)	(0.217)	(0.205)	(0.205)	(0.217)	(0.204)
ATH × HU_l	0.015	0.015	0.014	0.014	0.009	0.017
	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)	(0.049)
ATH × **ln**($RRI_{l,t-12}$)	-0.004	-0.004	-0.004	-0.004	-0.005	-0.004
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
HU_l× **ln**($RRI_{l,t-12}$)	-0.233***	-0.235***	-0.236***	-0.146***	-0.241***	-0.223***
	(0.031)	(0.031)	(0.031)	(0.038)	(0.031)	(0.031)
ATH ×HU_l× **ln**($RRI_{l,t-12}$)	-0.003	-0.003	-0.003	-0.003	-0.002	-0.004
	(0.010)	(0.010)	(0.010)	(0.010)	(0.011)	(0.010)
Fixed MSA Effect	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y
F-Stat	83619	83619	83619	83619	83205	83974
R-sq	0.99	0.99	0.99	0.99	0.99	0.99
Observation	1376	1376	1376	1376	1376	1376

Notes: (a) Median values. This table reports the results of the second equation in the simultaneous system. Office supply ($\ln(S_{l,t})$) is the dependent variable. Real rent index ($\ln(RRI_{l,t-12})$), real operating expense ($\ln(ROPEX_{l,t-12})$), search effort level ($SEL_{l,t-1}$), economic mismatch rate ($MR_{l,t-1}$), capitalization minus mortgage rates ($CM_{l,t-2}$), recession period dummy, and hurricane related dummies (ATH and HU_l) including interaction terms with lagged real rent index as well as interaction terms of MSA with lagged rent are independent variables. Signs ***, **, * represent significant level at 1%, 5%, 10% respectively.

Economic Mismatch and Search Effort Level

The equilibrium state of the search and matching process is represented by the long-run equations of economic mismatch rate and search effort level in Tables 3.6c and 3.6d. The inclusion of interaction terms related to office supply and real rent in these two long-run equations causes significant differences in the estimation results across models M2, M3 and M4. Because the search and matching process is unlikely to be heterogeneous across MSAs, the interaction of MSA dummies with office supply and/or real rents may lead to over-identification. As a consequence, the results estimated in model M1 are found to be more reliable and plausible.

A 1% increase in office stock reduces the economic mismatch rate by 0.05 in value (i.e. linear-log relationship), corresponding to a 0.83% drop if compared to its average value. A 1% increase in real personal income per capita, city size (measured by population) and ratio of employment to population leads to respectively a decrease of 1.05%, an increase of 0.71%, and an increase of 0.27% in mismatch rates. Furthermore, in the recession period, economic mismatch rates rise by 2.51%.

Search effort level is explained (at 1% significant level) by real rents, office stock and real income per capita, whose 1% rise reduces the required search effort by 0.51% and 9.7% and increases it by 4.38%. We hereby find evidence of strategic games played by landlords who may wait for better deals to happen in the future, holding vacant space and hence increasing the search effort in periods of higher income per capita. In addition, a greater quantity of property offers listed in the market may lead to a reduction in search effort instead of prolonging the decision process to consider more choices. Finally, we test for a possible endogeneity issue of the search effort level equation by conducting the Hausman test on the error term, and the results confirm that this variable is exogenous in our system of equations as assumed in our main model.

Table 3.6c: Panel C: Long Run Relationship of Mismatch Rate ($MR_{l,t}$)

Independent Variable	**M1**	**M2**	**M3**	**M4**	**M5**
Constant	28.487**	322.569***	28.449**	321.280***	28.388**
	(12.094)	(49.556)	(12.095)	(49.604)	(12.095)
ln($S_{l,t-1}$)	-3.888**	-18.371^{a}	-3.845*	-18.489^{a}	-3.885**
	(1.977)		(1.977)		(1.977)
ln($RIPC_{l,t-1}$)	-4.896***	-7.145***	-4.865***	-7.134***	-4.849***
	(1.389)	(1.606)	(1.389)	(1.607)	(1.390)
ln($EMP_{l,t-1}$)	1.241	4.378***	1.205	4.253***	1.164
	(1.128)	(1.478)	(1.128)	(1.479)	(1.129)
ln($POPI_{l,t-1}$)	3.333**	-3.188	3.251**	-3.121	3.275**
	(1.621)	(3.051)	(1.621)	(3.053)	(1.621)
Recession Period	0.117*	0.082	0.117*	0.079	0.117*
	(0.068)	(0.064)	(0.068)	(0.064)	(0.068)
MSA Dummy × **ln**($S_{l,t-1}$)	N	Y	N	Y	N
Fixed MSA Effect	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y
F-Stat	31.80	27.31	31.79	27.26	31.79
R-sq	0.64	0.70	0.64	0.70	0.64
Observation	1376	1376	1376	1376	1376

Notes: (a) Median values. This table reports the results of the third equation in the simultaneous system. Economic mismatch rate ($MR_{l,t}$) is the dependent variable. Office supply ($\ln(S_{l,t-1})$), real personal income per capita ($\ln(RIPC_{l,t-1})$), employment in office using sectors to population ($\ln(EMP_{l,t-1})$), population index ($\ln(POPI_{l,t-1})$) and recession period dummy are independent variables. Signs ***, ** and * represent significant level at 1%, 5% and 10% respectively.

Table 3.6d: Panel D: Long Run Relationship of Search Effort Level ($SEL_{l,t}$)

Independent Variable	**M1**	**M2**	**M3**	**M4**	**M6**
Constant	12.160***	12.154***	11.364	10.148	12.119***
	(2.102)	(2.102)	(14.285)	(14.285)	(2.102)
ln($RRI_{l,t-1}$)	-0.187*	-0.183*	1.052[a]	1.028[a]	-0.192*
	(0.103)	(0.103)			(0.103)
ln($S_{l,t-1}$)	-3.539***	-3.538***	-4.816[a]	-4.742[a]	-3.529***
	(0.390)	(0.390)			(0.390)
ln($RIPC_{l,t}$)	1.599***	1.594***	1.241***	1.248***	1.604***
	(0.271)	(0.271)	(0.330)	(0.330)	(0.271)
Recession Period	-0.002	-0.002	0.006	0.006	-0.002
	(0.014)	(0.014)	(0.012)	(0.012)	(0.014)
MSA dummy × **ln**($S_{l,t-1}$)	N	N	Y	Y	N
MSA dummy × **ln**($RRI_{l,t-1}$)	N	N	Y	Y	N
Fixed MSA Effect	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y
F-Stat	63.62	63.62	51.34	51.32	63.63
R-sq	0.78	0.78	0.86	0.86	0.78
Observation	1376	1376	1376	1376	1376

Notes: (a) Median values. This table reports the results of the fourth equation in the simultaneous system. Search effort level ($SEL_{l,t}$) is the dependent variable. Real rent index ($\ln(RRI_{l,t-1})$), office supply ($\ln(S_{l,t-1})$), real personal income per capita ($\ln(RIPC_{l,t})$) and recession period dummy are independent variables. Signs ***, ** and * represent significant level at 1%, 5% and 10% respectively.

Importance of Search and Matching Process

Based on Pedroni test results, we cannot omit economic mismatch rate and search effort level in the system of simultaneous equations at the same time. Both economic mismatch rate and search effort level plays a dominant role in the search and matching process. The comparison among M1, M5 and M6 reflects this phenomenon and suggests that exclusion of economic mismatch rate or search effort level leads to moderate changes in significance of hurricane effect. Although there are no obvious differences about the importance of search and matching process, one more MSA records negative supply elasticities estimated using M5 and M6. Even if considering a Bayesian Information Criteria, M6 seems the best fit, as the presence of a higher number of negative supply elasticities suggests the existence of possible biases in these estimates when the economic mismatch rate is omitted.

Estimated Long-Run Elasticities of Supply and Demand

We rely on coefficients of interaction terms for each MSA with lagged supply and real rent to estimate demand and supply elasticities by MSA. Table 3.7 reports all estimates for both dataset43 and dataset30. Focusing on the larger dataset and findings from model M1, the supply elasticities range between -0.17 and 0.38 and show less pronounced skewers than demand elasticities that range between -3.85 and +1.35. We summarize our estimations in a map (Figure 3.2), which shows our geographical coverage (corresponding to an overall 47% of the entire US population and almost 60% of the office workforce). All markets are supply inelastic and a negative supply elasticity estimated for San Jose, Charlotte, and San Francisco as well as New York implies no response of supply to changes in real rents. Because of no zoning or loose zoning laws, Houston and Fort Lauderdale are the least inelastic.

As far as demand elasticities are concerned, six MSAs (Charlotte, Fort Worth, Washington DC, Austin, Raleigh and West Palm Beach) are demand elastic and the vast majority are demand inelastic. We find a surprising positive demand elasticity in San Francisco, Denver, Dallas and Houston which may reflect a "Veblen effect" (i.e. signalling theory) where wealthy individuals consume more when the price is higher so as to advertise their business and achieve a greater status (Baowell et al 1996[22]). San Francisco, as the best-known CBD in the West region, may actually exhibit its Grade A offices as Veblen goods. More than 60% of office space is prime quality graded and a relatively strong Veblen effect would influence the overall rent. At the same time, San Francisco is the most supply inelastic, suggesting the possibility that landlords in this market hold some vacant space to gain from a higher future rental income. This strategy may clearly coexist with the Veblen effect. Denver, Dallas and Houston are the hubs of regional offices in West and South regions. More than half of office space is prime quality graded. Therefore, Veblen effect may also exist in these MSAs although supply elasticities are higher than San Francisco.

We also estimate elasticity for dataset30 with models including construction costs. Comparing the estimates with the larger dataset, we respectively find a wider range of supply and demand elasticities. The presence of a high correlation (+0.8) between the two sets of estimates supports our choice to exclude real construction costs to expand our study to a larger number of MSAs (from 30 to 43).

A final discussion of the regulatory and geographical constraints that may cause cross-sectional differences in the supply elasticity estimates are reported after the section on robustness tests.

Table 3.7: Estimates of Long Run Supply and Demand Elasticity of the Office Market by MSA

Model	**Dataset30**		**Dataset43**	
MSA	**Supply**	**Demand**	**Supply**	**Demand**
San Jose	-0.176***	-0.591	-0.172***	-0.576
Charlotte	-0.145***	-1.429	-0.147***	-1.353
San Francisco			-0.033***	0.288***
New York	0.201	-0.340*	-0.002***	-0.363
Denver	-0.005***	1.057***	0.007***	0.966***
Pittsburgh	0.009***	-0.512	0.012***	-0.485
Ventura			0.013***	-0.315***
Phoenix	0.025***	-0.617	0.021***	-0.603
Seattle	0.019***	-0.919	0.029***	-0.877
Boston	0.028***	-0.484	0.036***	-0.514
Baltimore	-0.046***	-0.700	0.055**	-0.669
San Diego	0.064***	-0.381**	0.062***	-0.389**
Sacramento	0.071***	-0.375***	0.067***	-0.376***
Fort Worth	0.052***	-3.584	0.071*	-3.380
Orlando			0.072***	-0.477*
Orange County			0.081**	-0.184**
Los Angeles	0.087**	-0.252***	0.091*	-0.269***
Newark			0.101*	-0.130***
Dallas	0.093	1.352***	0.108	1.346***
Jacksonville			0.122	-0.728
Washington, DC	0.101	-4.309	0.125	-3.847
Long Island			0.127	-0.221***
Oakland	0.125	-0.316*	0.130	-0.341
Cleveland	0.126	-0.190***	0.132	-0.193***
St. Louis	0.146	-0.398**	0.138	-0.390**
Kansas City	0.163	-0.349**	0.143	-0.350**
Philadelphia	0.341***	-0.543	0.144	-0.554
Austin			0.150	-1.310
Atlanta	0.169***	-0.930**	0.151***	-0.891**
Detroit	0.181	-0.036***	0.165	-0.036***
Raleigh			0.171	-1.010
Stamford			0.204	-0.405
Trenton			0.205	-0.922
Columbus	0.150	-0.300***	0.244***	-0.297***
Indianapolis			0.248***	-0.335***
Chicago	0.464***	-0.496	0.254***	-0.498
Cincinnati	0.205	-0.302***	0.278***	-0.298***
Tampa	0.199	-0.455*	0.29***	-0.449*
Wilmington			0.292***	-0.185***
West Palm Beach			0.317***	-2.309
Houston	0.293***	1.226***	0.378***	1.325***
Fort Lauderdale			0.380***	-0.663

Notes: Negative value in supply elasticity is interpreted as no response of supply to change in office rent. Signs ***, ** and * represent significant levels at 1%, 5%, 10% respectively.

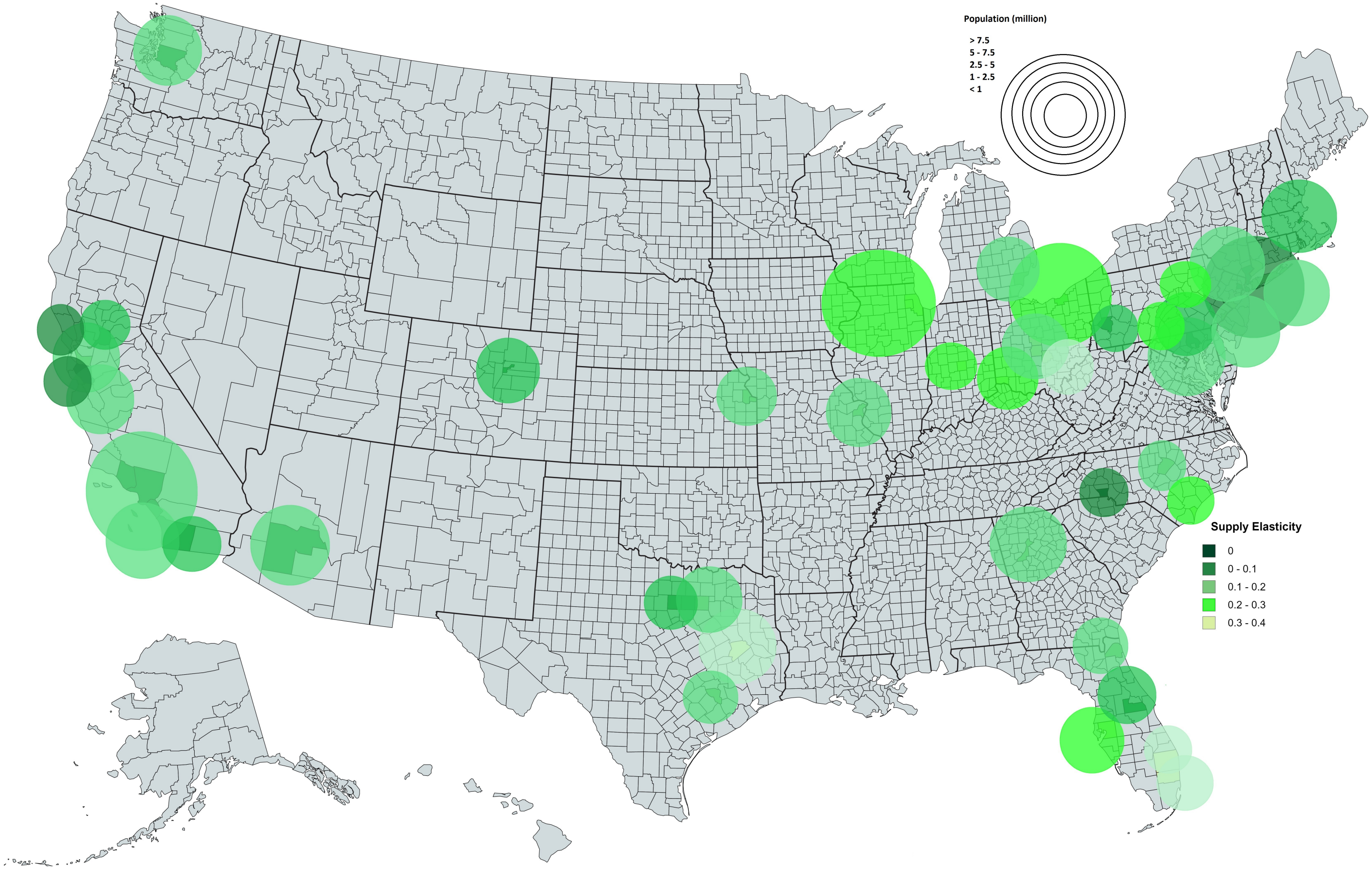


Figure 3.2: Map Chart of Supply Elasticity in 42 MSAs

Unobserved Heterogeneity

We include MSA fixed effects in four simultaneous equations and the majority of MSAs have statistically significant results (see Table 3.8). This implies that we successfully capture unobserved heterogeneity in the model. Unobserved heterogeneity may include overall property age or tenants' preferences in terms of property characteristics that information is not available. After including MSA fixed effects, we have high R^2 in the model.

Table 3.8: Significance of MSA Fixed Effect

MSA	Equation			
	ln($RRI_{l,t}$)	**ln**($S_{l,t}$)	$MR_{l,t}$	$SEL_{l,t}$
Austin	-2.756	-1.242***	-4.772*	-4.603***
Baltimore	0.498	0.643***	-2.596	-3.569***
Boston	4.302	0.825***	4.275***	0.450***
Charlotte	-2.625	0.238	-5.385**	-3.928***
Chicago	5.388	0.061	2.445**	1.516***
Cincinnati	8.085***	-0.399*	-4.014**	-3.279***
Cleveland	15.004***	-0.908***	-2.882	-3.574***
Columbus	5.806*	-0.871***	-6.033**	-5.394***
Dallas	-9.468***	0.305	1.736***	0.099
Denver	-10.395***	0.293	0.180	-1.575***
Detroit	110.940***	-0.779***	-3.458**	-2.236***
Fort Lauderdale	-0.348	-1.582***	-5.582*	-5.862***
Fort Worth	-4.236	-1.341***	-6.561*	-6.354***
Houston	-9.193***	0.160	2.510***	-0.068
Indianapolis	4.938*	-0.816***	-3.995	-5.076***
Jacksonville	-1.225	-1.733***	-8.415**	-6.639***
Kansas City	5.394	-1.053***	-5.125**	-3.898***
Long Island	10.108**	-1.367***	-3.396	-5.899***
Los Angeles	13.880***	0.582***	1.270*	0.888***
Miami	-2.129	-0.050	-5.119**	-4.064***
New York	11.295*	2.000***	5.196**	4.062***
Newark	25.486***	-0.633***	0.267	-3.328***
Oakland	5.979	-0.866***	-2.124	-4.065***
Orange County	17.418**	-0.317**	0.278	-2.722***
Orlando	2.216	-0.999***	-5.988**	-4.655***
Philadelphia	2.873	-0.220	0.825	-1.309***
Phoenix	1.814	-0.006	-4.01***	-2.034***
Pittsburgh	3.355	0.031	-1.177	-2.288***
Raleigh	-1.545		-4.672**	-3.672***
Sacramento	4.822*	-0.781***	-4.216*	-4.264***
San Diego	4.865	-0.466***	-2.212	-3.444***
San Francisco	-22.019***	0.434***	1.539	-2.490***
San Jose	0.414	0.215	-3.657	-5.064***
Seattle	-0.664	0.088	-0.994	-2.116***
St. Louis	4.157	-1.140***	-3.955*	-4.268***
Stamford	2.766	-1.667***	0.326	-6.160***
Tampa	2.792	-0.814***	-5.436**	-4.492***
Trenton	-3.180	-1.612***	-8.962*	-9.318***
Ventura	0.503	-2.499***	-8.685	-11.402***
Washington, DC	-4.363	0.903***	5.643***	1.870***
West Palm Beach	-4.144*	-1.379***	-5.476	-6.752***
Wilmington	8.159***	-1.942***	-9.151*	-8.507***

Note: Signs ***, ** and * represent significant levels at 1%, 5% and 10% respectively.

Likelihood of Changes in Frictional Vacancy

As for non-prime vacant space, if an economic mismatch can switch to a physical one (and vice versa), a change in frictional vacancy may occur. To capture this switch, we add the condition that major refurbishments may be carried out in the equations of supply and economic mismatch rate. We create dummy variables of asking rental gaps from 10% to 60% and also investigate the impacts of lagged asking rental gaps on supply and economic mismatch rate (i.e. 4, 6 and 8 quarter lag). We find that the asking rental gap of 40% with 6 quarter lag generate the most statistically significant results referring to table 3.9. Results related to rental gap with different number of quarter lag can be found in the Appendix - tables 3.17 to 3.19.

For the supply equation, the lagged asking rental gaps increase the overall supply. Assuming that refurbishment takes one and a half years, the interaction term $(GRG40_{l,t-4} \times MR_{l,t})$ shows that refurbished space brings a negative adjustment to economic mismatch on supply as a decrease in frictional vacancy (indicated by the interaction term) leads to an increase in overall supply. Although we are able to capture changes in frictional vacancy into the model, a moderate alteration is found in coefficients of interaction terms between MSAs and lagged real rent, with moderate changes in estimated supply elasticity as a result. As far as the mismatch rate equation is concerned, we do find evidence that the economic mismatch is lower when refurbishment options are more likely to be exercised and it becomes higher after one and a half years because physical mismatch may turn into an economic mismatch after the actual refurbishment takes place.

Table 3.9: Long Run Relationships - Likelihood of Change in Frictional Vacancy with Different Gross Rental Gap (6 Quarter Lag)

	GRG10	**GRG20**	**GRG30**	**GRG40**	**GRG50**	**GRG60**
Panel A: Supply(ln($S_{l,t}$))						
$MR_{l,t}$	-0.007***	-0.005***	-0.002***	-0.003***	-0.003***	-0.003***
	(0.002)	(0.001)	(0.0005)	(0.0004)	(0.0004)	(0.0004)
$GRG_{l,t-6}$	-0.031***	-0.011***	0.008**	0.034***	0.030***	-0.077
	(0.009)	(0.004)	(0.003)	(0.007)	(0.010)	(0.053)
$GRG_{l,t-6} \times MR_{l,t}$	0.006***	0.003***	-0.0008	-0.004***	-0.004**	0.010
	(0.002)	(0.0007)	(0.0005)	(0.001)	(0.002)	(0.007)
MSA dummy $\times$ **ln(**$RRI_{l,t-12}$**)**	Y	Y	Y	Y	Y	Y
F-Stat	81250	81041	83003	85284	82580	82078
R-sq	0.99	0.99	0.99	0.99	0.99	0.99
Panel B: Mismatch Rate($MR_{l,t}$**)**						
$GRG_{l,t-6}$	0.243	0.00005	0.018	0.455***	0.783***	-0.044
	(0.153)	(0.077)	(0.089)	(0.148)	(0.177)	(0.376)
MSA dummy $\times$ **ln(**$S_{l,t-1}$**)**	N	N	N	N	N	N
F-Stat	31.55	31.56	31.51	31.85	32.19	31.54
R-sq	0.64	0.64	0.64	0.64	0.65	0.64
Interaction Terms in SEL	N	N	N	N	N	N
Fixed MSA Effect	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.

3.6.2 Short Run Dynamics

Among all models, M1 is the best fit for the long-run equilibrium; therefore, we build short-run equations using M1 and excluding fixed time and MSA effects. We present four versions of the same model with inclusion/ exclusion of recession period or occurrence of hurricanes from the Atlantic Ocean. All four systems obtain results in line with theoretical predictions, where changes in supply and mismatch rate negatively affect real rents, and ratio of employment to population and real income per capita are positively related to rents. Table 3.10 summarizes the speed of adjustment. All models find that 16.1-16.4% of real rents adjust to equilibrium every quarter. In other words, full adjustment to equilibrium of real rents might take approximately 6.2 quarters. All models also obtain similar results for the short-run supply equation. The adjustment speed for office supply is lower than the one for rents as it is estimated to be around 12.6% per quarter, i.e. equilibrium reached within 7.9 quarters.

The adjustment speed in the search and matching process is higher than for supply. Particularly, 21.5% and 15.5% per quarter are adjusted in the economic mismatch and search effort, respectively, suggesting a shorter period (4.7 and 6.5 quarters) necessary to reach the long-run equilibrium. This finding may imply that landlords tend to control the search and matching process instead of responding to the market through development activities. Their strategy adjusts structural vacancy, which affects adjusted office supply. If the adjustment speed in the supply equation includes vacancy adjustment and delivery speed of new development, the supply adjustment to equilibrium would be much slower than for the economic mismatch due to a low construction speed. We obtain related empirical evidence by estimating the speed of adjustment for dataset30. Referring to table 3.15b in the Appendix, much lower speed to equilibrium (7.2%) is found in supply when models include real construction costs. As 13.9 quarters are necessary to reach an equilibrium state, we argue that the adjustment period is prolonged if landlords build new developments to respond to demand shocks.

Finally considering the likelihood of changes in frictional vacancy, similar results for the short-run models are found, with a slight increase in the speed of adjustment to long-run equilibrium in the supply equation (by 0.3 quarter). We also present the full results of short run models in the Appendix (see tables 3.13a to 3.13d).

Table 3.10: Short Run: Speed of Adjustment (Panel A)

Error Correction Term	Quarterly Adjustment	Quarters to Long-Run Equilibrium
Real Rent	16.1%	6.2
Office Supply	12.6%	7.9
Mismatch Rate	21.5%	4.7
Search Effort Level	15.5%	6.5

3.6.3 Robustness Tests

In this section, we present a series of further results where we test the robustness of our main models.

Inclusion of Construction Costs and Impact of Innovations

To include residential construction costs (as a proxy of office construction costs) in our estimation models and test for demand and supply disruptions due to technological innovation of tenants, we use a restricted sample of 30 MSAs (dataset30), which show time series data on construction costs and employment figures in information industries (i.e. we assume that higher innovation of tenants leads to higher depreciation of office properties as tenants need to change the setting of their offices in order to fit in the latest technology). First, we find that a 1% increase in real construction costs has an economically negligible impact on office supply (i.e. -0.003-0.005%), while other coefficients (incl. the one for real estate operating expenses) do not change significantly. Second, a 1% change in employment in information industries determines a +0.34-0.35% change in real rents, which is in line with the effect we find for the ratio of general employment in the office sector to population. We, therefore, find confirmation that our main results hold and are not affected by technology-driven demand shocks. For parsimonious reasons we only report a full set of results in the Appendix - tables 3.14a to 3.14d and 3.15a to 3.15d.

First Difference Models and Mismatch Rate Measure

As a further step in our analysis, we estimate models using first differences rather than levels. Since this approach does not allow us to separate long- and short-run models, we only present one set of estimations. Model R1 mirrors the specification of model M1 in our original estimation. In model R2, we use a different mismatched rate measure, defined as the ratio between *available but occupied stock* and *vacant stock*.

Results are consistent with our original models but they show homogeneous trends across MSAs (i.e. coefficients for interaction terms are not significant in either rent or supply equations) when both theoretical predictions and previous findings in the literature suggest heterogeneity - see Tables 3.11a and 3.11b (Panels A to D). Therefore, we find confirmation that long- and short-run dynamics should be jointly modelled using an Engle-Granger based error correction model with variables in levels. This result also suggests that the MSA heterogeneity of demand and supply responses may be different in the long- and short-term. Finally, our results are robust to the use of the alternative mismatch rate measure except mismatch rates with different definitions make opposite impact on real rent. Similar findings are also obtained for dataset30, and results are reported in the Appendix - tables 3.16a and 3.16b.

Table 3.11a: First Difference Models of Long Run Relationships: Real Rent & Office Stock

Panel A: Real Rent		
Independent Variable	**R1**	**R2**
Constant	-0.003	-0.003
	(0.004)	(0.004)
$\Delta ln(S_{l,t-1})^a$	0.095	0.173
$\Delta ln(EMP_{l,t-2})$	0.528***	0.538***
	(0.056)	(0.056)
$\Delta ln(RIPC_{l,t-4})$	0.199***	0.204***
	(0.034)	(0.034)
$\Delta MR(1)_{l,t-1}$	-0.001	
	(0.001)	
$\Delta MR(2)_{l,t-1}$		0.0003**
		(0.0001)
Recession Period	-0.005***	-0.005**
	(0.001)	(0.001)
ATH	0.008***	0.008***
	(0.001)	(0.001)
F-Stat	4.21	4.25
BIC - Simultaneous System	-14946	-9373
R-sq	0.22	0.22
Observation	1333	1333

Panel B: Office Stock		
Independent Variable	**R1**	**R2**
Constant	0.006***	0.006***
	(0.001)	(0.001)
$\Delta ln(RRI_{l,t-12})^a$	-0.010	0.001
$\Delta ln(ROPEX_{l,t-12})$	0.009***	0.009***
	(0.002)	(0.002)
$\Delta SEL_{l,t-1}$	-0.0001	-0.00004
	(0.001)	(0.001)
$\Delta MR(1)_{l,t-1}$	-0.0003	
	(0.0002)	
$\Delta MR(2)_{l,t-1}$		-0.0001**
		(0.00002)
$\Delta CM_{l,t-2}$	-0.001	-0.001
	(0.001)	(0.001)
Recession Period	-0.0003	-0.0004
	(0.0003)	(0.0003)
ATH	-0.001	-0.001
	(0.001)	(0.001)
HU_l	0.002	0.002
	(0.001)	(0.001)
ATH $\times HU_l$	0.0001	0.0001
	(0.001)	(0.001)
ATH $\times \Delta ln(RRI_{l,t-12})$	0.031**	0.031**
	(0.014)	(0.014)
$HU_l \times \Delta ln(RRI_{l,t-12})$	0.031	-0.036
	(0.069)	(0.077)
ATH$\times HU_l \times \Delta ln(RRI_{l,t-12})$	-0.027	-0.026
	(0.028)	(0.028)
F-Stat	4.78	4.81
R-sq	0.31	0.31
Observation	1333	1333

Notes:
(a) Median values.
MR(1) is the mismatch rate computed by (available but occupied stock / total stock). MR(2) is the mismatch rate computed by (available but occupied stock / vacant stock).
***, ** and * represent significant level at 1%, 5%, and 10% respectively.

Table 3.11b: First Difference Models of Long Run Relationships: Mismatch Rate & Search Effort Level

Panel C: Mismatch Rate		
Independent Variable	**R1**	**R2**
Constant	0.040	-0.109
	(0.163)	(1.319)
$\Delta ln(S_{l,t-1})$	-15.864***	-123.699***
	(3.816)	(30.863)
$\Delta ln(RIPC_{l,t-1})$	-0.152	17.354
	(1.845)	(14.964)
$\Delta ln(EMP_{l,t-1})$	-0.863	-23.138
	(2.463)	(19.972)
$\Delta ln(POPI_{l,t-1})$	32.883	206.505
	(22.526)	(182.677)
Recession Period	0.026	0.039
	(0.045)	(0.365)
F-Stat	1.76	1.14
R-sq	0.09	0.06
Observation	1333	1333

Panel D: Search Effort Level		
Independent Variable	**R1**	**R2**
Constant	-0.003	-0.003
	(0.027)	(0.026)
$\Delta ln(RRI_{l,t-1})$	0.018	0.019
	(0.17)	(0.17)
$\Delta ln(S_{l,t-1})$	-0.514	-0.517
	(0.724)	(0.724)
$\Delta ln(RIPC_{l,t})$	-0.259	-0.25
	(0.387)	(0.388)
Recession Period	-0.012	-0.011
	(0.009)	(0.009)
F-Stat	1.76	2.43
R-sq	0.09	0.12
Observation	1333	1333

Notes:
MR(1) is the mismatch rate computed by (available but occupied stock / total stock) which is used in model R1. MR(2) is the mismatch rate computed by (available but occupied stock / vacant stock) which is used in model R2.
***, ** and * represent significant level at 1%, 5%, and 10% respectively.

Hurricane Effects

Hurricane affected areas may also be represented by port cities or cities which lack transportation infrastructure (proxied by commuting time). To test the appropriateness and interpretation of our hurricane measure (which may be capturing other factors linked to transportation), we include dummies of port cities or cities with lack of transportation infrastructure in model M1 and only report results of real rent and supply equations in table 3.12. We find that all original coefficients in the rent equation do not change significantly but the interaction term of hurricane threatened area with rent changes sign in the supply equation. Port cities or lack of transportation infrastructure may also affect office supply, however the inclusion of port cities and cities with lack of transportation infrastructure worsens the estimates of office supply elasticities. Therefore, we confirm our identification of hurricane risk and occurrence that should be only included in our main model.

Table 3.12: Panel A: Robustness Check On Hurricane Effects

Panel A: Real Rent	**H1**	**H2**	**H3**
Recession Period	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)
ATH_t	0.009***	0.009***	0.009***
	(0.002)	(0.002)	(0.002)
$PORT_l$		11.295*	
		(5.937)	
$TTWD_l$			11.295*
			(5.937)
MSA dummy $\times$ **ln**$(S_{l,t-1})$	Y	Y	Y
F-Stat	76.73	76.73	76.73
BIC - Simultaneous System	-8200	-8200	-8200
R-sq	0.83	0.83	0.83
Observation	1376	1376	1376

Panel B: Supply	**H1**	**H2**	**H3**
ATH_t			0.038*
			(0.02)
HU_l	-0.019	-1.631***	-1.631***
	(0.205)	(0.217)	(0.217)
$ATH_t \times HU_l$	0.015	0.015	0.015
	(0.049)	(0.049)	(0.049)
$ATH_t \times$ **ln**$(RRI_{l,t-12})$	-0.004	-0.004	-0.004
	(0.004)	(0.004)	(0.004)
$HU_l \times$ **ln**$(RRI_{l,t-12})$	-0.233***	0.146***	-0.136***
	(0.031)	(0.028)	(0.038)
$ATH_t \times HU_l \times$ **ln**$(RRI_{l,t-12})$	-0.003	-0.003	-0.003
	(0.01)	(0.01)	(0.01)
$PORT_l$		-0.22	
		(0.277)	
$PORT_l \times$ **ln**$(RRI_{l,t-12})$		-0.152***	
		(0.03)	
$TTWD_l$			0.061
			(0.183)
$TTWD_l \times$ **ln**$(RRI_{l,t-12})$			-0.184***
			(0.032)
MSA dummy $\times$ **ln**$(RRI_{l,t-12})$	Y	Y	Y
F-Stat	83619	83619	83619
R-sq	0.99	0.99	0.99
Observation	1376	1376	1376

Notes:
Signs ***, **, * represent significant level at 1%, 5%, 10% respectively.

Imposing Constraints to Avoid Negative Supply Elasticities
We impose four constraints on three interaction terms of MSAs (Charlotte, New York, San Francisco, and San Jose) with lagged rents in the supply equation to avoid negative supply elasticities. We confirm the robustness of our main results finding similar coefficients and significance in all estimates of supply and demand elasticities.

Extended Sample Period
Our dataset could be extended to 1998 with the exception of the economic mismatch rate, which is only available from 2005. Hence, we compare the estimates using our main and extended sample periods (respectively starting from 2005 and 1998) using a three-equation system with real rents, supply, and search effort. Our results with the extended sample period are not significantly different from the original ones.
At the same time, dropping the fourth equation from our system worsens the estimates of supply elasticities. We, therefore, find confirmation that the search and matching model is important to determine agents' responsiveness to price changes, and it should be included in our system of equations.

3.7 Final Discussion on Supply Elasticities

To justify our estimation of office supply elasticity in forty-two MSAs[10], we need to determine the geographical and regulatory constraints, which are respectively linked to the following two questions:

(1) Are new CBDs likely to emerge?

(2) How tight is the building density and height restriction in existing CBDs?

As far as the first question is concerned, land availability increases the likelihood of new CBDs forming. The Spearman's rank correlation coefficient between undevelopable area as measured by Saiz (2010)[149][11] and our estimated office supply elasticity is -0.25 at an 85% confidence level. Land scarcity reduces the elasticity of both residential and commercial real estate supply. Among three MSAs with perfectly inelastic office supply, San Jose and San Francisco (refer to Panel B) contain more than 50% of the undevelopable area. Furthermore, Ventura - one of top 10 supply inelastic MSAs - contains the most undevelopable area - almost 80%. All of them are coastal cities that imply geographic constraints driven

[10]One out of 43 MSAs (Miami) is automatically omitted while regressing the models for estimating elasticities. Therefore, we can estimate supply elasticities for 42 MSAs.

[11]Saiz(2010) estimated the area within the cities' 50-kilometer radii corresponding to wetlands, lakes, rivers or other internal water bodies to quantify land availability.

by the Pacific Ocean. The coastal barrier is also supported by Rose's finding (1989)[147], which was obtained using a different approach to measure the area net of water bodies. As a result, developing new CBDs to replenish office supply is unlikely feasible.

Since topology is not the only source of supply constraints, Charlotte and Baltimore - with almost no natural barriers - show very inelastic office supply. Extremely strong monopoly zoning power stored in these MSAs deters the supply response. Based on three calibrations of monopoly power of zoning governments including two concentration ratios of four largest suburb urbanization areas and counts of zoning governments conducted by Rose (1989), these MSAs retain the greatest monopoly zoning power, which crucially determines the tightness of height restrictions or redevelopment. In contrast, more than 200 zoning governments are involved in New York City, Chicago, and Philadelphia, and low concentration ratios are also seen in Columbus, Los Angeles and St Louis. Relatively less inelastic supply elasticity is estimated in these office markets (with the exception of New York City, which shows stricter height restrictions as discussed below). Therefore, the strength of monopoly zoning power gives responses to both questions.

Furthermore, "regulatory shadow tax" is an alternative approach to proxy for the tightness of regulatory constraints specifically driven by building height restrictions and it directly responds to our second question. Bertaud and Brueckner (2005)[26], Glaeser et al. (2005)[88], and Cheshire and Hilber (2008)[39] claimed that height restrictions imposed by governments minimize externalities, and the difference in price setting between regulated and unregulated markets (i.e. price minus marginal cost of construction) can be used to quantify the degree of restrictions' so-called "regulatory tax". Glaeser et al. (2005)[88] investigated height restrictions in housing markets in the US and found that zero regulatory taxes are present in some cities (e.g. Houston, Detroit, Pittsburgh, Philadelphia and Tampa). They then measured constraints of the office market in Manhattan only (i.e. 0 in trough period and 0.5 in peak period); however, these estimates may not be used to explain our office supply elasticities because the gap between market price and marginal cost is sometimes explained by the monopoly power held by developers in industries that are not very competitive. Cheshire and Hilber (2008)[39] analysed UK office markets and adopted a similar approach to quantify regulatory tax due to height restriction finding that regulatory constraints in London are much tighter than in Manhattan. We assume regulatory taxes in office markets are positively proportional to housing markets and therefore deduce that height restrictions in the US could be weaker than those in London.

Finally, cross-sectional differences of supply elasticities across MSAs are also attributed to competition between states or cities driven by the incentives to local government revenues. Since sale and individual income taxes are the most important sources of state government revenues, governments are motivated to develop cosmopolitan CBDs to attract highly skilled residents. Rivalry among neighbouring state governments may exist and regulatory constraints of office space supply may be weaker in states with higher CBD status. For example, New York and Boston offer incentives (i.e. low tax rates) to attract human capital and, as a result, they find a larger proportion of the labour force is highly educated relative to Philadelphia (Gyourko et al 2005)[98]. Moreover, the access to mobility leads firms to choose their location in highly competitive cities and, as a result, Glaeser (2005)[86] showed Boston being the most skilled city. If local governments in Philadelphia decide to enhance the city's competitiveness to attract both firms and talents, they may relax constraints on the supply of commercial real estate to a certain degree. This implies a relatively less inelastic supply in Philadelphia compared with New York and Boston. Overall, we find that regulatory constraints may be moderately adjusted based on fiscal conditions of local governments.

3.8 Conclusion

Our research contributes to the studies related to supply constraints in several ways. Firstly, we build a conceptual framework distinguishing between physical and economic mismatch to obtain an estimation of frictional and structural vacancy as main components of the natural vacancy rate similar to the labour market literature. Secondly, we adopt an empirical strategy, which allows us to distinguish between long- and short-run dynamics and obtain supply elasticities at the MSA level that are found to be correlated with the housing market elasticities obtained in previous studies. Particularly, our estimations are highly correlated with the Wharton's residential regulatory constraints (WRLURI) and housing supply elasticities measured by Saks (2008) and Wheaton et al. (2014) - please refer to Table 3.1.

We conclude that US office markets are generally supply inelastic, with San Jose, Charlotte, San Francisco and New York (dataset43) as well as Denver and Baltimore (dataset30) showing a perfectly inelastic supply that could be explained by land unavailability and monopoly zoning power. In contrast, MSAs without zoning, such as Houston and Tampa, show a relatively high supply elasticity, although still below one. Moreover, in San Francisco, we find a Veblen effect, which could be explained by the presence of landlords strategically holding vacant space to seek for higher future rents. To achieve precise estimations, we identify economic mismatch by observing occupied space that is listed to be re-leased (i.e. signalling a mismatch with an existing tenant). Furthermore, we build a model to link the search and matching process with a framework of the fundamental real estate cycle. The empirical strategy is not limited to estimate supply and demand elasticity, but it simultaneously attempts to estimate structural vacancy rates.

So far our estimated structural vacancy and supply elasticity are positively correlated (Spearman rank correlation of +0.27). These results may show that the low controlling power of landlords reduces the flexibility in adjusting equilibrium vacancies to respond to market shocks and, therefore, supply elasticity tends to be mostly explained by regulatory and geographical constraints. Landlords' controlling power varies over the cycle - in a boom period controlling power is stronger than in a bust period - and hoarding may more likely occur in a boom period.

Finally, we also attempt to capture the likelihood of change in frictional vacancy in our empirical strategy and find confirmation of our previous results. In fact, considering frictional vacancy in an equilibrium model may improve our existing strategy as we may be able to deliver insightful research on the linkages between supply constraints and specific types of vacancy (i.e. structural and frictional) sequentially.

3.9 Appendix

For panel dataset30, twelve models are compiled. Models B1, B4, B7, and B10 contain a variable of general employment in office using sectors in rent equations. In the models B2, B5, B8, and B11, this variable is replaced by employment in information industries. Population is added to rent equations in other models. Supply elasticity in only 28 MSAs is estimated.

Table 3.13a: Panel A: Short Run Relationship of Real Rent ($\Delta ln(RRI_{l,t})$)

Independent Variable	**M1a**	**M1b**	**M1c**	**M1d**
Constant	-0.003***	0.0003	-0.007***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
$\Delta ln(S_{l,t-1})$	-0.123	-0.049	-0.074	-0.022
	(0.113)	(0.112)	(0.11)	(0.11)
$\Delta ln(EMP_{l,t-2})$	0.481***	0.405***	0.505***	0.445***
	(0.051)	(0.052)	(0.05)	(0.051)
$\Delta ln(RIPC_{l,t-4})$	0.202***	0.200***	0.186***	0.186***
	(0.033)	(0.032)	(0.032)	(0.032)
$\Delta MR_{l,t-1}$	-0.0003	-0.0003	-0.0002	-0.0003
	(0.001)	(0.001)	(0.001)	(0.001)
$ECT^{RRI}_{l,t-1}$	-0.161***	-0.164***	-0.162***	-0.164***
	(0.012)	(0.012)	(0.012)	(0.012)
Recession Period		-0.006***		-0.005***
		(0.001)		(0.001)
ATH			0.009***	0.008***
			(0.001)	(0.001)
F-Stat	85.93	79.46	86.22	77.75
R-sq	0.23	0.25	0.27	0.28
Observation	1333	1333	1333	1333

Notes: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
All four versions of the model keep consistent results. The impacts of short term change in supply and employment become weaker when the dummy of Atlantic Ocean hurricane occurrence is included in the model. In contrast, the effect of recession period becomes weaker by comparing M1b with M1d. Overall, coefficients of error correction term of real rent almost remain same.

Table 3.13b: Panel B: Short Run Relationship of Office Stock ($\Delta ln(S_{l,t})$)

Independent Variable	**M1a**	**M1b**	**M1c**	**M1d**
Constant	0.003***	0.002***	0.002***	0.002***
	(0.0001)	(0.0002)	(0.0002)	(0.0002)
$\Delta ln(RRI_{l,t-12})$	0.023***	0.023***	0.022***	0.022***
	(0.005)	(0.005)	(0.006)	(0.005)
$\Delta ln(ROPEX_{l,t-12})$	0.010***	0.010***	0.010***	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
$\Delta SEL_{l,t-1}$	-0.004***	-0.004***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
$\Delta MR_{l,t-1}$	-0.0001	-0.0001	-0.0001	-0.0001
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
$\Delta CM_{l,t-2}$	0.001**	0.001*	0.001**	0.0005
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
$ECT^{S}_{l,t-1}$	-0.126***	-0.129***	-0.126***	-0.128***
	(0.013)	(0.013)	(0.013)	(0.013)
Recession Period		0.001***		0.001***
		(0.0002)		(0.0003)
ATH			0.0004	0.0006**
			(0.0002)	(0.0003)
F-Stat	25.27	24.42	22.1	22.22
R-sq	0.10	0.12	0.11	0.12
Observation	1333	1333	1333	1333

Notes: Signs ***, **, * represent significant level at 1%, 5%, 10% respectively.
All four versions of the model maintain consistent results. Error correction term makes the strongest impact on short term change in office supply in terms of magnitude.

Table 3.13c: Panel C: Short Run Relationship of Mismatch Rate ($\Delta MR_{l,t}$)

Independent Variable	**M1a**	**M1b**	**M1c**	**M1d**
Constant	0.06**	0.026	0.061**	0.027
	(0.027)	(0.031)	(0.027)	(0.031)
$\Delta ln(S_{l,t-1})$	-4.666	-5.155	-4.729	-5.216
	(3.329)	(3.335)	(3.329)	(3.335)
$\Delta ln(RIPC_{l,t-1})$	1.151	1.188	1.099	1.125
	(0.983)	(0.982)	(0.983)	(0.981)
$\Delta ln(EMP_{l,t-1})$	-8.055***	-7.070***	-8.038***	-7.063***
	(1.516)	(1.587)	(1.515)	(1.587)
$\Delta ln(POPI_{l,t-1})$	6.697	6.618	6.492	6.453
	(8.355)	(8.339)	(8.351)	(8.336)
$ECT^{MR}_{l,t-1}$	-0.215***	-0.214***	-0.214***	-0.214***
	(0.017)	(0.017)	(0.017)	(0.017)
Recession Period		0.075**		0.075**
		(0.033)		(0.033)
F-Stat	35.89	30.99	35.86	30.98
R-sq	0.12	0.12	0.12	0.12
Observation	1333	1333	1333	1333

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
All four versions of model keep consistent results. Short term effects of supply and population on mismatch rate are very negatively significant. Coefficients of error correction terms of mismatch rate are the highest comparing rent, supply and search effort level.

Table 3.13d: Panel D: Short Run Relationship of Search Effort Level ($\Delta SEL_{l,t}$)

Independent Variable	**M1a**	**M1b**	**M1c**	**M1d**
Constant	0.029***	0.03***	0.029***	0.031***
	(0.003)	(0.005)	(0.003)	(0.005)
$\Delta ln(RRI_{l,t-1})$	0.159	0.153	0.162	0.156
	(0.135)	(0.135)	(0.135)	(0.135)
$\Delta ln(S_{l,t-1})$	-2.227***	-2.196***	-2.271***	-2.238***
	(0.635)	(0.637)	(0.635)	(0.637)
$\Delta ln(RIPC_{l,t})$	0.347*	0.298	0.311*	0.267
	(0.182)	(0.218)	(0.182)	(0.218)
$ECT^{SEL}_{l,t-1}$	-0.155***	-0.155***	-0.156***	-0.156***
	(0.017)	(0.017)	(0.017)	(0.017)
Recession Period		-0.003		-0.004
		(0.007)		(0.007)
F-Stat	25.81	20.71	25.8	20.8
R-sq	0.08	0.08	0.08	0.08
Observation	1333	1333	1333	1333

Notes: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
All four versions of the model keep consistent results. The impact of short term change in supply on the first difference in search effort level is the most significant among other variables.

Table 3.14a: Panel A: Long Run Relationship of Real Rent ($\ln(RRI_{l,t})$)-Dataset30

Independent Variable	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
Constant	8.838***	5.785**	4.854*	9.152***	6.281***	5.385**	8.644***	5.583**	4.744*	8.931***	6.056***	5.24**
	(2.414)	(2.296)	(2.435)	(2.416)	(2.438)	(2.438)	(2.417)	(2.299)	(2.439)	(2.418)	(2.302)	(2.441)
ln($S_{l,t-1}$)[a]	-1.985	-1.485	-1.323	-1.885	-1.515	-1.365	-2.042	-1.518	-1.398	-1.925	-1.548	-1.431
ln($EMP_{l,t-2}$)	0.606***			0.599***			0.609***			0.602***		
	(0.064)			(0.064)			(0.064)			(0.064)		
ln($INEMI_{l,t-2}$)		0.342***	0.339***		0.339***	0.337***		0.346***	0.344***		0.343	0.341***
		(0.028)	(0.029)		(0.028)	(0.029)		(0.029)	(0.029)		(0.029)	(0.029)
ln($POPI_{l,t-2}$)			-0.143			-0.139			-0.126			-0.124
			(0.129)			(0.129)			(0.129)			(0.129)
ln($RIPC_{l,t-4}$)	0.62***	0.975***	1.009***	0.616***	0.967***	0.9997***	0.622***	0.978***	1.008***	0.619***	0.97***	0.999***
	(0.079)	(0.054)	(0.062)	(0.079)	(0.054)	(0.062)	(0.079)	(0.055)	(0.062)	(0.079)	(0.054)	(0.062)
$MR_{l,t-1}$	-0.002	-0.005**	-0.005***	-0.003	-0.006***	-0.006***	-0.002	-0.005**	-0.005***	-0.003	-0.005***	-0.005**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Recession Period	-0.006*	-0.010***	-0.010***	-0.006*	-0.010***	-0.010***	-0.006*	-0.010***	-0.010***	-0.006*	-0.010***	-0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
ATH	0.008***	0.008***	0.008***	0.008*	0.008***	0.008***	0.008***	0.008***	0.008***	0.009***	0.008*	0.008***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
MSA dummy $\times$ **ln**($S_{l,t-1}$)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed MSA Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
F-Stat	78.62	83.64	82.54	78.7	83.75	82.65	78.56	83.64	82.54	78.64	83.76	82.65
BIC - Simultaneous System	-5978	-6018	-6008	-6025	-6065	-6055	-5950	-5994	-5983	-5993	-6038	-6027
R-sq	0.84	0.85	0.85	0.84	0.85	0.85	0.84	0.85	0.85	0.84	0.84	0.85
Observation	960	960	960	960	960	960	960	960	960	960	960	960

Notes: (a) Median values. Signs ***, **, * represent significant level at 1%, 5%, 10% respectively.
We investigate the effect of technological innovation of tenants on office market dynamics. Comparing models (B1 vs B2; B4 vs B5; B7 vs B8; and B10 vs B11), an inclusion of employment in the information industry as a proxy of technological innovation reflects smaller impact of technological innovation relative to general employment. The impact even becomes a bit less significant after including population in models B3, B6, B9 and B12. Moreover, an inclusion of population leads to the negative impacts of supply on real rent less significant respectively.

Table 3.14b: Panel B: Long Run Relationship of Office Supply ($\ln(S_{l,t})$)-Dataset30

Independent Variable	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
Constant	4.171***	4.181***	4.176***	4.165***	4.174***	4.17***	4.182***	4.193***	4.189***	4.178***	4.188***	4.184***
	(0.123)	(0.123)	(0.124)	(0.123)	(0.123)	(0.124)	(0.124)	(0.124)	(0.124)	(0.124)	(0.124)	(0.124)
$\ln(RRI_{l,t-12})^a$	0.113	0.092	0.091	0.098	0.093	0.092	0.092	0.088	0.087	0.093	0.089	0.088
$\ln(RSI_{l,t-12})$	-0.004	-0.004	-0.003	-0.004	-0.004	-0.004	-0.005	-0.004	-0.004	-0.005	-0.004	-0.004
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$\ln(ROPEX_{l,t-12})$	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$SEL_{l,t-1}$	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.011***	-0.010***	-0.010***	-0.010***	-0.010***	-0.010***	-0.010***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$MR_{l,t-1}$	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
$CM_{l,t-2}$	0.013***	0.013***	0.016***	0.013***	0.013***	0.013***	0.014***	0.014***	0.014***	0.014***	0.014***	0.014***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Recession Period	0.0006	0.0006	0.0006	0.0005	0.0006	0.0006	0.0005	0.0006	0.0006	0.0005	0.0006	0.0006
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
ATH_t			0.039	0.041*		0.040	0.040		0.038	0.041	0.039	
			(0.025)	(0.025)		(0.025)	(0.025)		(0.025)	(0.025)	(0.025)	
HU_l	-0.783***	0.740***	-0.786***	-0.766***	-0.771***	0.749***	0.796***	-0.746***	-0.744***	-0.729***	0.759***	0.767***
	(0.183)	(0.207)	(0.183)	(0.183)	(0.183)	(0.207)	(0.207)	(0.184)	(0.184)	(0.183)	(0.208)	(0.208)
$ATH_t \times HU_l$	-0.006	-0.007	-0.008	-0.006	-0.006	-0.007	-0.005	-0.005	-0.006	-0.004	-0.005	-0.006
	(0.060)	(0.061)	(0.061)	(0.060)	(0.061)	(0.061)	(0.060)	(0.061)	(0.061)	(0.060)	(0.061)	(0.061)
$ATH_t \times \ln(RRI_{l,t-12})$	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005	-0.005
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
$HU_l \times \ln(RRI_{l,t-12})$	-0.147***	-0.146***	-0.147***	-0.151***	-0.150***	-0.150***	-0.156***	-0.155***	-0.155***	-0.159***	-0.158***	-0.158***
	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)
$ATH_t \times HU_l \times \ln(RRI_{l,t-12})$	0.002	0.002	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.001	0.001
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
$TTWD_l$	-0.058	-0.095	-0.095	-0.042	0.135	-0.078	-0.053	0.120	0.121	-0.042	-0.081	0.118
	(0.285)	(0.285)	(0.285)	(0.284)	(0.286)	(0.285)	(0.285)	(0.191)	(0.191)	(0.285)	(0.285)	(0.191)
$TTWD_l \times \ln(RRI_{l,t-12})$	-0.214***	-0.214***	-0.216***	-0.216***	-0.216***	-0.218***	-0.215***	-0.215***	-0.217***	-0.216***	-0.216***	-0.218***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.033)	(0.034)	(0.034)
MSA dummy $\times \ln(RRI_{l,t-12})$	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed MSA Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
F-Stat	51089	51089	51089	51089	51089	51089	51089	51089	51089	51089	51089	51089
R-sq	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Observation	960	960	960	960	960	960	960	960	960	960	960	960

Notes: (a) Median values. Signs ***, **, * represent significant level at 1%, 5%, 10% respectively.
In general, all versions of model maintain consistent results except for hurricane threatened area and travel time to work. Comparing with the results based on dataset43, the estimates of coefficients do not have significant changes.

Table 3.14c: Panel C: Long Run Relationship of Mismatch Rate ($MR_{l,t}$)-Dataset30

Independent Variable	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Constant	35.258***	35.193***	35.215***	283.621***	279.971***	279.556***	34.929***	34.869***	34.885***	282.608***	279.215***	278.832***
	(12.789)	(12.786)	(12.786)	(47.649)	(47.631)	(47.635)	(12.799)	(12.796)	(12.796)	(47.815)	(47.798)	(47.802)
ln($S_{l,t-1}$)	-4.609**	-4.608**	-4.573**	-18.671^a	-18.205^a	-18.130^a	-4.459**	-4.449**	-4.418**	-17.719^a	-17.377^a	-17.265^a
	(2.139)	(2.138)	(2.139)				(2.140)	(2.139)	(2.140)			
ln($RIPC_{l,t-1}$)	-2.923*	-2.930*	-2.936*	-4.396***	-4.333**	-4.318**	-2.788*	-2.798*	-2.803*	-4.371**	-4.314**	-4.302**
	(1.517)	(1.517)	(1.517)	(1.709)	(1.707)	(1.707)	(1.519)	(1.518)	(1.518)	(1.712)	(1.710)	(1.710)
ln($EMP_{l,t-1}$)	-2.293*	-2.312*	-2.307*	1.178	1.055	1.067	-2.501**	-2.526*	-2.523**	0.956	0.826	0.834
	(1.242)	(1.242)	(1.242)	(1.608)	(1.606)	(1.606)	(1.245)	(1.245)	(1.245)	(1.612)	(1.610)	(1.610)
ln($POPI_{l,t-1}$)	-0.689	-0.680	-0.715	-4.212	-3.852	-4.023**	-0.990	-0.991	-1.022	-4.549	-4.231	-4.368
	(1.907)	(1.906)	(1.907)	(3.903)	(3.899)	(3.903)	(1.911)	(1.910)	(1.911)	(3.912)	(3.909)	(3.912)
Recession Period	0.075	0.075	0.075	0.002	0.0001	-0.0002	0.075	0.075	0.075	0.0003	-0.001	-0.002
	(0.074)	(0.074)	(0.074)	(0.068)	(0.068)	(0.068)	(0.074)	(0.074)	(0.074)	(0.068)	(0.068)	(0.068)
MSA dummy × **ln**($S_{l,t-1}$)	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y
Fixed MSA Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
F-Stat	25.32	25.36	25.36	25.32	25.37	25.37	25.32	25.37	25.37	25.29	25.34	25.34
R-sq	0.63	0.63	0.63	0.71	0.71	0.71	0.63	0.63	0.63	0.71	0.71	0.71
Observation	960	960	960	960	960	960	960	960	960	960	960	960

Notes:
(a) Median values across 30 MSAs.
(b) Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
An inclusion of interaction terms of MSA with office supply causes significant differences in estimated coefficients. As discussed, the search and matching process is unlikely to be heterogeneous across MSAs, the interaction of MSA dummies with office supply may lead to over-identification. Therefore, the results estimated in models B1, B2 and B3 are more reliable.

Table 3.14d: Panel D: Long Run Relationship of Search Effort Level ($SEL_{l,t}$)-Dataset30

Independent Variable	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Constant	13.358***	13.172***	13.193***	13.338***	13.153***	13.174***	-4.893	-5.424	-5.299	-6.969	-7.464	-7.338
	(2.377)	(2.377)	(2.377)	(2.377)	(2.377)	(2.377)	(14.200)	(14.192)	(14.193)	(14.202)	(14.195)	(14.195)
ln($RRI_{l,t-1}$)	-0.426***	-0.425***	-0.433***	-0.439***	-0.438***	-0.446***	0.770^{a}	0.821^{a}	0.821^{a}	0.776^{a}	0.829^{a}	0.830^{a}
	(0.115)	(0.115)	(0.115)	(0.115)	(0.115)	(0.115)						
ln($S_{l,t-1}$)	-3.648***	-3.622***	-3.619***	-3.643***	-3.617***	-3.614***	-3.481^{a}	-3.481^{a}	-3.494^{a}	-3.483^{a}	-3.492^{a}	-3.504^{a}
	(0.431)	(0.431)	(0.431)	(0.431)	(0.431)	(0.431)						
ln($RIPC_{l,t}$)	1.726***	1.739***	1.741***	1.741***	1.754***	1.756***	1.741***	1.736***	1.735***	1.736***	1.732***	1.731***
	(0.295)	(0.295)	(0.295)	(0.295)	(0.295)	(0.295)	(0.361)	(0.361)	(0.361)	(0.361)	(0.361)	(0.361)
Recession Period	-0.023	-0.023	-0.023	-0.023	-0.023	-0.023	-0.020	-0.020	-0.020	-0.019	-0.019	-0.019
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
MSA dummy × **ln**($S_{l,t-1}$)	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
MSA dummy × **ln**($RRI_{l,t-1}$)	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
Fixed MSA Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
F-Stat	66.19	65.86	65.80	66.20	65.88	65.82	55.18	55.24	55.25	55.17	55.23	55.24
R-sq	0.81	0.81	0.81	0.81	0.81	0.81	0.87	0.87	0.87	0.87	0.87	0.87
Observation	960	960	960	960	960	960	960	960	960	960	960	960

Notes:
(a) Median values across 30 MSAs.
(b) Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.

Table 3.15a: Panel A: Short Run Relationship of Real Rent ($\Delta ln(RRI_{l,t})$)-Dataset30

Independent Variable	**B1**	**B2**	**B3**
Constant	-0.002**	-0.0004	-0.002
	(0.001)	(0.001)	(0.001)
$\Delta ln(S_{l,t-1})$	-0.154	-0.426***	-0.451***
	(0.163)	(0.163)	(0.167)
$\Delta ln(EMP_{l,t-2})$	0.559***		
	(0.064)		
$\Delta ln(INEMI_{l,t-2})$		0.238***	0.236***
		(0.035)	(0.035)
$\Delta ln(POPI_{l,t-2})$			0.474
			(0.402)
$\Delta ln(RIPC_{l,t-4})$	0.216***	0.311***	0.314***
	(0.041)	(0.041)	(0.042)
$\Delta MR_{l,t-1}$	-0.002	-0.003**	-0.003**
	(0.001)	(0.001)	(0.001)
$ECT^{RRI}_{l,t-1}$	-0.168***	-0.175***	-0.170***
	(0.016)	(0.016)	(0.016)
F-Stat	63.55	52.06	42.46
R-sq	0.23	0.20	0.20
Observation	930	930	930

Notes: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
Comparing models B2 with B1, the change in first difference of employment in information industry has less significant positive impact on short term change in real rent relative to the ratio of general office using employment to population.

Table 3.15b: Panel B: Short Run Relationship of Office Stock ($\Delta ln(S_{l,t})$)-Dataset30

Independent Variable	**B1**	**B2**	**B3**
Constant	0.003***	0.003***	0.003***
	(0.0001)	(0.0001)	(0.0001)
$\Delta ln(RRI_{l,t-12})$	0.022***	0.023***	0.023***
	(0.006)	(0.006)	(0.006)
$\Delta ln(RSI_{l,t-12})$	-0.005*	-0.005	-0.005
	(0.003)	(0.003)	(0.003)
$\Delta ln(ROPEX_{l,t-12})$	0.007***	0.007***	0.007***
	(0.002)	(0.002)	(0.002)
$\Delta SEL_{l,t-1}$	-0.003***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)
$\Delta MR_{l,t-1}$	-0.0002	-0.0002	-0.0002
	(0.0002)	(0.0002)	(0.0002)
$\Delta CM_{l,t-2}$	0.001***	0.001***	0.001***
	(0.0004)	(0.0004)	(0.0004)
$ECT^{S}_{l,t-1}$	-0.072***	-0.072***	-0.072***
	(0.013)	(0.013)	(0.013)
F-Stat	11.08	11.37	11.31
R-sq	0.08	0.08	0.08
Observation	930	930	930

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
The estimates are consistent among three versions of models. Error correction terms generate the most significant impact on short term change in office stock.

Table 3.15c: Panel C: Short Run Relationship of Mismatch Rate ($\Delta MR_{l,t}$)-Dataset30

Independent Variable	**B1**	**B2**	**B3**
Constant	0.068**	0.067**	0.066**
	(0.030)	(0.030)	(0.030)
$\Delta ln(S_{l,t-1})$	-3.921	-4.116	-4.160
	(4.181)	(4.181)	(4.182)
$\Delta ln(RIPC_{l,t-1})$	1.594	1.596	1.596
	(1.058)	(1.059)	(1.059)
$\Delta ln(EMP_{l,t-1})$	-8.691***	-9.011***	-9.017***
	(1.657)	(1.657)	(1.657)
$\Delta ln(POPI_{l,t})$	1.638	2.055	2.624***
	(9.649)	(9.651)	(9.664)
$ECT^{MR}_{l,t-1}$	-0.215***	-0.216***	-0.216***
	(0.02)	(0.02)	(0.02)
F-Stat	26.76	27.29	27.31
R-sq	0.13	0.13	0.13
Observation	930	930	930

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
All versions of models estimate consistent results. Short term changes in office supply and ratio of office using employment to population make the most significant impact on short term changes in mismatch rate.

Table 3.15d: Panel D: Short Run Relationship of Search Effort Level ($\Delta SEL_{l,t}$)-Dataset30

Independent Variable	**B1**	**B2**	**B3**
Constant	0.028***	0.029***	0.029***
	(0.004)	(0.004)	(0.004)
$\Delta ln(RRI_{l,t-1})$	0.119	0.128	0.126
	(0.147)	(0.147)	(0.147)
$\Delta ln(S_{l,t-1})$	-2.303***	-2.316***	-2.316***
	(0.834)	(0.834)	(0.834)
$\Delta ln(RIPC_{l,t})$	0.493**	0.484**	0.482**
	(0.207)	(0.207)	(0.207)
$ECT_{l,t-1}^{SEL}$	-0.169***	-0.170***	-0.171***
	(0.020)	(0.020)	(0.020)
F-Stat	20.59	20.71	20.80
R-sq	0.09	0.09	0.09
Observation	930	930	930

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.
All versions of models estimate consistent results. Short term changes in office supply make the most significant impact on short term changes in mismatch rate.

Table 3.16a: First Difference Models of Long Run Relationships: Real Rent & Office Stock - Dataset30

Panel A: Real Rent		
Independent Variable	**R1**	**R2**
Constant	-0.003	-0.004
	(0.004)	(0.004)
$\Delta ln(S_{l,t-1})^a$	0.061	0.123
$\Delta ln(EMP_{l,t-2})$	0.610***	0.622***
	(0.071)	(0.071)
$\Delta ln(RIPC_{l,t-4})$	0.202***	0.205***
	(0.043)	(0.043)
$\Delta MR(1)_{l,t-1}$	-0.002	
	(0.001)	
$\Delta MR(2)_{l,t-1}$		0.0002**
		(0.0002)
Recession Period	-0.004***	-0.004**
	(0.001)	(0.001)
ATH	0.008***	0.008***
	(0.001)	(0.001)
F-Stat	4.17	4.15
BIC - Simultaneous System	-10881	-7103
R-sq	0.22	0.22
Observation	930	930

Panel B: Office Stock		
Independent Variable	**R1**	**R2**
Constant	0.005***	0.005***
	(0.001)	(0.001)
$\Delta ln(RRI_{l,t-12})^a$	0.00003	-0.009
$\Delta ln(RSI_{l,t-12})$	-0.003	-0.003
	(0.004)	(0.004)
$\Delta ln(ROPEX_{l,t-12})$	0.006***	0.006***
	(0.002)	(0.002)
$\Delta SEL_{l,t-1}$	0.0004	0.0005
	(0.001)	(0.001)
$\Delta MR(1)_{l,t-1}$	-0.0004*	
	(0.0002)	
$\Delta MR(2)_{l,t-1}$		-0.00005
		(0.00003)
$\Delta CM_{l,t-2}$	0.001	0.001
	(0.001)	(0.001)
Recession Period	-0.0002	-0.0002
	(0.0003)	(0.0003)
ATH	-0.003***	-0.002
	(0.001)	(0.001)
HU_l	0.003***	0.003***
	(0.001)	(0.001)
ATH $\times HU_l$	0.0001	0.0001
	(0.0005)	(0.0005)
ATH $\times \Delta ln(RRI_{l,t-12})$	0.033**	0.033**
	(0.014)	(0.014)
$HU_l \times \Delta ln(RRI_{l,t-12})$	0.023	0.028
	(0.056)	(0.052)
ATH$\times HU_l \times \Delta ln(RRI_{l,t-12})$	-0.041	-0.039
	(0.028)	(0.028)
$TTWD_l$	0.0004	0.0005
	(0.001)	(0.001)
$TTWD_l \times \Delta ln(RRI_{l,t-12})$	-0.041	-0.002
	(0.049)	(0.044)
F-Stat	4.79	4.77
R-sq	0.34	0.34
Observation	930	930

Notes:
(a) Median values.
MR(1) is the mismatch rate computed by (available but occupied stock / total stock). MR(2) is the mismatch rate computed by (available but occupied stock / vacant stock).
***, ** and * represent significant level at 1%, 5%, and 10% respectively.

Table 3.16b: First Difference Models of Long Run Relationships: Mismatch Rate & Search Effort Level - Dataset30

Panel C: Mismatch Rate		
Independent Variable	**R1**	**R2**
Constant	-0.122	-1.745
	(0.168)	(1.281)
$\Delta ln(S_{l,t-1})$	-14.817***	-71.392**
	(4.774)	(36.355)
$\Delta ln(RIPC_{l,t-1})$	0.322	22.823
	(1.937)	(14.759)
$\Delta ln(EMP_{l,t-1})$	-2.101	-17.857
	(2.846)	(21.687)
$\Delta ln(POPI_{l,t-1})$	73.057***	562.121***
	(26.620)	(202.846)
Recession Period	0.004	-0.005
	(0.049)	(0.373)
F-Stat	1.8	1.09
R-sq	0.11	0.07
Observation	930	930

Panel D: Search Effort Level		
Independent Variable	**R1**	**R2**
Constant	-0.017	-0.017
	(0.028)	(0.028)
$\Delta ln(RRI_{l,t-1})$	-0.038	-0.036
	(0.183)	(0.183)
$\Delta ln(S_{l,t-1})$	0.013	0.012
	(0.960)	(0.960)
$\Delta ln(RIPC_{l,t})$	0.025	0.019
	(0.428)	(0.428)
Recession Period	-0.013	-0.013
	(0.010)	(0.010)
F-Stat	2.59	2.59
R-sq	0.15	0.15
Observation	1333	1333

Notes:
MR(1) is the mismatch rate computed by (available but occupied stock / total stock) which is used in model R1. MR(2) is the mismatch rate computed by (available but occupied stock / vacant stock) which is used in model R2.
***, ** and * represent significant level at 1%, 5%, and 10% respectively.

Table 3.17: Long Run Relationships - Likelihood of Change in Frictional Vacancy with Different Gross Rental Gap (4 Quarter Lag)

	GRG10	**GRG20**	**GRG30**	**GRG40**	**GRG50**	**GRG60**
Panel A: Supply(ln($S_{l,t}$))						
$MR_{l,t}$	0.001	-0.005***	-0.002***	-0.003***	-0.003***	-0.003***
	(0.002)	(0.001)	(0.0005)	(0.0004)	(0.0004)	(0.0004)
$GRG_{l,t-4}$	0.020**	-0.009**	0.017***	0.040***	0.034***	-0.025
	(0.008)	(0.004)	(0.003)	(0.006)	(0.008)	(0.044)
$GRG_{l,t-4} \times MR_{l,t}$	-0.003****	0.002***	-0.002***	-0.005***	-0.004***	0.003
	(0.0015)	(0.0007)	(0.0005)	(0.001)	(0.001)	(0.006)
MSA dummy $\times$ **ln($RRI_{l,t-12}$)**	Y	Y	Y	Y	Y	Y
F-Stat	83666	82101	85556	87056	83497	81969
R-sq	0.99	0.99	0.99	0.99	0.99	0.99
Panel B: Mismatch Rate($MR_{l,t}$)						
$GRG_{l,t-4}$	0.468***	-0.115	0.089	0.356**	0.438**	-0.263
	(0.157)	(0.079)	(0.085)	(0.142)	(0.175)	(0.346)
MSA dummy $\times$ **ln($S_{l,t-1}$)**	N	N	N	N	N	N
F-Stat	31.72	31.60	31.51	31.75	31.75	31.56
R-sq	0.64	0.64	0.64	0.64	0.64	0.64
Interaction Terms in SEL	N	N	N	N	N	N
Fixed MSA Effect	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.

Table 3.18: Long Run Relationships - Likelihood of Change in Frictional Vacancy with Different Gross Rental Gap (8 Quarter Lag)

	GRG10	**GRG20**	**GRG30**	**GRG40**	**GRG50**	**GRG60**
Panel A: Supply(ln($S_{l,t}$))						
$MR_{l,t}$	-0.010***	-0.004***	-0.003***	-0.003***	-0.003***	-0.003***
	(0.002)	(0.001)	(0.0005)	(0.0004)	(0.0004)	(0.0004)
$GRG_{l,t-8}$	-0.041***	-0.008**	0.001	0.014**	0.025*	-0.054
	(0.009)	(0.004)	(0.003)	(0.007)	(0.014)	(0.074)
$GRG_{l,t-8} \times MR_{l,t}$	0.008***	0.002**	-0.0001	-0.001	-0.004*	0.006
	(0.002)	(0.001)	(0.0006)	(0.001)	(0.002)	(0.010)
MSA dummy $\times$ **ln($RRI_{l,t-12}$)**	Y	Y	Y	Y	Y	Y
F-Stat	80021	81140	82098	82832	82202	82084
R-sq	0.99	0.99	0.99	0.99	0.99	0.99
Panel B: Mismatch Rate($MR_{l,t}$)						
$GRG_{l,t-8}$	0.194	0.124	-0.160*	0.222	0.762***	-0.384
	(0.149)	(0.077)	(0.091)	(0.151)	(0.179)	(0.429)
MSA dummy $\times$ **ln($S_{l,t-1}$)**	N	N	N	N	N	N
F-Stat	31.56	31.64	31.64	31.60	32.14	31.57
R-sq	0.64	0.64	0.64	0.64	0.65	0.64
Interaction Terms in SEL	N	N	N	N	N	N
Fixed MSA Effect	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.

Table 3.19: Long Run Relationships - Likelihood of Change in Frictional Vacancy with Different Gross Rental Gap

	GRG40(n=4)	**GRG50(n=4)**	**GRG40(n=6)**	**GRG50(n=6)**	**GRG40(n=8)**	**GRG50(n=8)**
Panel A: Supply(ln($S_{l,t}$))						
$MR_{l,t}$	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
$GRG_{l,t-n}$	0.040***	0.034***	0.034***	0.030***	0.014**	0.025*
	(0.006)	(0.008)	(0.007)	(0.010)	(0.007)	(0.014)
$GRG_{l,t-n} \times MR_{l,t}$	-0.005***	-0.004***	-0.004***	-0.004**	-0.001	-0.004*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
MSA dummy $\times$ ln($RRI_{l,t-12}$)	Y	Y	Y	Y	Y	Y
F-Stat	87056	83497	85284	82580	82832	82202
R-sq	0.99	0.99	0.99	0.99	0.99	0.99
Panel B: Mismatch Rate($MR_{l,t}$)						
$GRG_{l,t-n}$	0.356**	0.438**	0.455***	0.783***	0.222	0.762***
	(0.142)	(0.175)	(0.148)	(0.177)	(0.151)	(0.179)
MSA dummy $\times$ ln($S_{l,t-1}$)	N	N	N	N	N	N
F-Stat	31.75	31.75	31.85	32.19	31.60	32.14
R-sq	0.64	0.64	0.64	0.65	0.64	0.65
Interaction Terms in SEL	N	N	N	N	N	N
Fixed MSA Effect	Y	Y	Y	Y	Y	Y
Fixed Time Effect	Y	Y	Y	Y	Y	Y

Note: Signs ***, ** and * represent significant level at 1%, 5%, 10% respectively.

Chapter 4

Modelling Interactive Mortgage Termination Strategies

4.1 Abstract

We build an installment option valuation model to price two types of early termination options written on commercial mortgages: default and prepayment. The key feature of our model is the introduction of MSA-specific supply constraints into the underlying real estate price process, which determines the value of early termination options. Our main contribution lies in the analogy between early mortgage termination and installment options with straddle like payoff, so as to enable the modelling the borrowers' ability to choose default (put) or prepayment (call) at a specific time. Our simulations find higher values of prepayment options relative to mortgage default that implies greater probability to prepay mortgages with intermediate balloon payments. We also price the default option as American continuous installment put options (if ignoring prepayment) and prepayment in cash as American continuous installment call options (if ignoring default), and we prove that tightening real estate supply constraints rises the value of early termination options by pricing their analogous options. Therefore, we suggest an alternative risk management measure for mortgage markets to be found in controlling real estate supply constraints.

4.2 Introduction

As US financial institutions face tightening requirements of risk-based capital for multifamily mortgages and heightening risk-based capital charges on high-volatility commercial real estate loans [1] starting from 2015 due to the implementation of the Basel Accord III, the risk exposure in commercial mortgages has been receiving more and more attention in financial markets. Unlike residential mortgages, more complicated designs in commercial mortgages bring more types of early termination options - default, restructuring, prepayment and defeasance[2] - that quantify mortgage risks. A significant impact on credit stability of financial institutions varying by types of early termination option in terms of loss exposure could be foreseen because commercial mortgage outstanding accounts for more than 15% of bank credits (equivalent to more than 45% of overall mortgages). This is also one of reasons for the potential need of a radical reform in regulations on commercial mortgages.

Theoretical models of residential mortgage default are mainly built up from changes in utility and consumption along the life-cycle of borrowers (Campbell and Cocco 2015 [35]; Gerardi, Rosen and Willen 2010 [83]; Piskorski and Tchistyi 2010 [136] and 2011 [137]). Due to the different nature of demand for leverage in commercial real estate investment, the theoretical framework of early mortgage terminations can be modelled as options using the Black & Scholes pricing model [28]. In the existing literature, the decisions to prepay and default are regarded as a call option and European put options respectively (Vandell 1995 [171], Ambrose, Buttimer and Capone 1997 [10]). [3] Particularly, the interaction between default and prepayment are investigated as a pair of competing risks (Deng, Quigley and Van Order 2000 [55]; Clapp, Deng and An 2006 [49]; Pennington-Cross 2010 [134]). We suggest that early mortgage termination is analogous to an installment option with straddle or strangle payoff that describes the choice between default and prepayment based on their option values. This approach helps capturing the interaction between default and prepayment. Moreover, we suggest that execution costs for mortgage default and prepayment are added to

[1] They are defined as loans for the purposes of acquisition, construction and development with 80% higher loan-to-value ratio and contributed capital from a borrower would account for less than 15% of the project's value according to the Mortgage Bankers Association.

[2] Defeasance value is estimated based on another project return which involves leverage of another mortgage. Restructuring involves modified mortgages that change boundary conditions of default and prepayment via interest rate reduction and maturity extension. As it requires complex assumptions in modelling, we relegate defeasance and restructuring for further research.

[3] In a series of papers, Kau, Keenan, Muller and Epperson suggested treating a mortgage contract as a compound option, however did not explain the principle in depth (1987 [112], 1992 [114] and 1995 [111]).

strike prices of default put and prepayment call options and the relative option values are computed considering execution costs.

Besides, Shiller et al. (2017 [155]) advocate continuous workout mortgages for reducing mortgage default. [4] Alternative mortgage products growing in the market offer flexibility to borrowers by altering payment schedules. The paradox of alternative home mortgage products enhancing benefits for borrowers is through smoothing consumption but this also embeds a significant default risk which was at origin of the recent mortgage crisis (Cocco 2010 [50]; LaCour-Little and Yang 2010 [118]). And the impact of deferred amortization can make the leverage effect even more hazy. Although we do not consider alternative mortgage products in this research, our new approach to quantify mortgage risks could also offer an insight into the design of these products. Moreover, mortgage modification or restructuring could create value for both borrowers and lenders by enhancing the efficiency (Agarwal et al. 2011 [5]; Piskorski and Tchistyi 2011). Our model can be easily extended to value mortgage restructuring options.

Our work contributes to the existing literature on the pricing of early termination options with three new approaches. First, we apply an American installment option valuation to value mortgage default and prepayment risks, where early mortgage termination is analogous to an installment option embedded with a straddle or strangle payoff and including stopping and early exercise boundaries, which indicate the maximum amount of negative equity that is tolerable before defaulting and the minimum of net property values that trigger prepayment. Second, we introduce constraints driven by the real estate supply elasticity of the collateral in the log normal stochastic process, so as to enhance pricing models for early termination options of commercial mortgages by considering more realistic real estate market dynamics. More specifically, we link the supply elasticity with the volatility of real estate prices. Third, we capture execution costs into the installment option valuation model by adding these to the strike prices of underlying options. We estimate implicit bankruptcy costs of mortgage default and for a range of imposed explicit prepayment penalties as execution costs for prepayment. This covers the entire decision paths of borrowers who intend to early terminate mortgages by valuing costs and benefits driven by different execution methods (i.e. default and prepayment).

We start developing a theoretical model, and then simulate option values of early mortgage terminations for constant payment mortgages (CPM) and interest only

[4] The continuous workout mortgage consists of fixed rate mortgage and negative equity insurance. The pricing model of a continuous workout mortgage considers prepayment and default options.

mortgages (IOM), as well as constant amortization mortgages (CAM) with intermediate balloon payments by Monte Carlo method. Early mortgage termination involves both default and prepayment, and its value is the sum of separate default and prepayment option values. In other words, joint default and prepayment generate benefits to mortgage borrowers as they can strategically select the best execution approach (default or prepayment) after valuing costs and benefits, as well as uncertainty of default and prepayment. All our simulation cases suggest that the prepayment option value is greater than the default option for all types of mortgages. Furthermore, we find that tightening underlying collateral property supply constraints increases the value of early termination options. An alternative risk management tool for mortgage markets could seek to control real estate supply constraints of the underlying collateral.
This chapter is organized as follows. The next section provides a literature review related to early termination options. Section 4.4 presents our theoretical model. Sections 4.5 and 4.6 describe the setup of simulations and parameterization, whose results and analysis are reported in section 4.7. Finally, we conduct scenario analysis for the two dimensional model and particularly discuss the impact of real estate supply elasticity on early mortgage termination, and we discuss our main conclusion in the last section.

4.3 Literature Review

If we exclude Kau et al. (1987[112], 1992[114] and 1995[111]), in the existing literature treating a mortgage contract as a series of interacting put and call options, mortgage default is regarded as a collection of European put options (Epperson et al. 1985 [65]): at each mortgage payment date, one put option with a strike price which is determined by contemporaneous net equity values is virtually written on a mortgage contract during origination and could be exercised only on a payment date. A borrower will exercise an option if property values are smaller than mortgage values or insolvency occurs. However, this analogy ignores actual linkages between options and hence it could mis-state values of default options.
The dynamic model to analyze decisions of home mortgage borrowers which include options to default, prepay or refinance a loan constructed by Campbell and Cocco (2015 [35]) emphasizes the role of negative home equity for mortgage default and the differential impact of heterogeneous characteristics of borrowers, for instance labour income growth and risk on termination decisions. This study shows that higher labour income risk leads to higher probabilities of default and

cash out prepayment for both adjustable and fixed rate mortgage borrowers and even higher if labour income risks are correlated with real interest rates. Labour income growth would not bring significant changes in probabilities of default, cash out and refinancing since effects of lower "incentives to save" cancel off the benefits from improving affordability. Apart from borrowers, heterogeneity of originators and special servicers could determine mortgage default particularly for commercial mortgages. Originators would adjust credit spreads to mortgage rates according to their financial conditions - those facing a sudden fall in their stock prices in quarters would levy higher credit spreads that generate higher probabilities of default (Titman et al. 2010[163] and Black et al. 2012[30]). Special servicers would make initial workout strategic decisions that alter the likelihood of mortgage default (Chen et al. 2012[37]). These reflect important roles of originators and special servicers in managing mortgage risks. Since the heterogeneity of real estate supply constraints the underlying collateral is never discussed, our work address its role in pricing early termination options.

Kau et al. (1987 [112], 1992 [114] and 1995 [111]) build generalized models for default and prepayment of fixed rate mortgages by using extended Black & Scholes model (1973 [28]) in which stochastic interest rates are assumed. In the exposition of the mortgage pricing problem, they briefly suggest the treatment of embedded options in a mortgage contract as a compound option, but they do not seem to specify the exact types of compound options. Ultimately, they set up boundary conditions and solve the Black-Scholes partial differential equation numerically for different scenarios that are used to deduce values of prepayment and default. They find that prepayment values are greater than default values in general. In this study, we argue that early mortgage termination options should be analogous to American continuous installment options because the options are still alive once scheduled mortgage payments as installments are made.

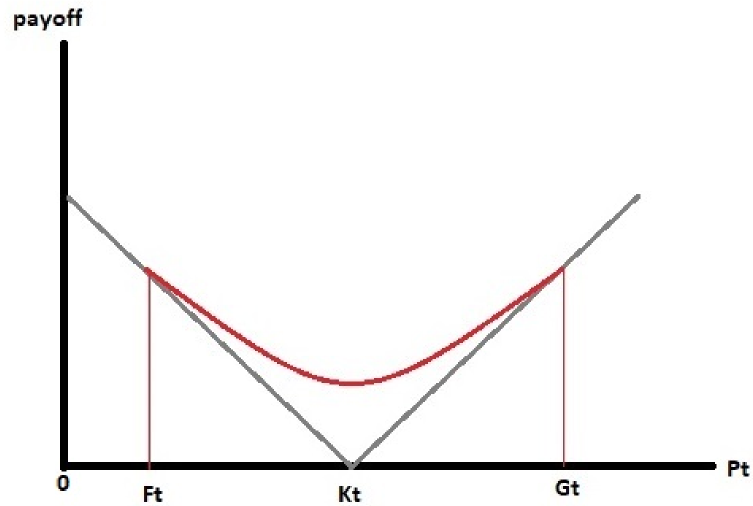
Unlike conventional competing risk analysis between prepayment and default (Ambrose and Sanders 2003 [15], Ciochetti et al. 2002 [44] and 2003 [45], Deng, Quigley and Van Order 2000 [55], Grovenstein et al. 2005 [95], Seslen and Wheaton 2010 [154] and An et al. 2013 [16]), the dynamic model built by Campbell and Cocco (2015 [35]) does not consider a risk interaction between prepayment and default, but they separately capture conditions of prepayment in terms of negative interest rates and accumulated positive home equity values, and conditions of default in terms of negative home equity. Our model, however, considers the interactions and obtains separate boundary conditions for the denial of mortgage obligations and early prepayments. Moreover, we compare boundary conditions of installment options with a straddle or strangle like payoff

(as interaction between default put and prepayment call options).
We describe the decision paths of mortgage borrowers opting for early mortgage termination with the detailed analysis of relative costs and benefits. This process is undertaken by borrowers who catch the opportunities to “strategic default", which refers to the borrower’s decision to stop making payments despite having the ability to do so (Bradley et al. 2015 [32], Favara et al. 2012 [71], Guiso et al.2013 [96], Mayer et al. 2014 [124]). The existing literature concludes that a negative equity position is the key driver of strategic default, but moral and social considerations as well as herding behaviour (e.g. neighbourhood with other strategic defaults) affect decisions to strategic default. In our research, we investigate what level of negative equity triggers default with the consideration of implicit bankruptcy costs. This also allows us to contribute to the literature related to strategic default.
Furthermore, options to prepay are usually regarded as American call options, since a borrower considers full prepayment in cash when market interest rates linked to refinancing are lower than mortgage rates. However, we argue that the feature of fixed exercise prices is not the most appropriate due to the time-varying nature of the remaining mortgage balance. American continuous installment call options are then suggested as the most appropriate tool.
The literature on the valuation of installment options is limited. Underlying assets for installment options are mostly foreign currencies, and installment options are usually classified as discrete or continuous cases (Ciurlia and Roko 2005[48], Griebsch et al. 2008[93], Ciurlia 2011[47]). Our study is the first attempt to apply installment options in the pricing of early mortgage termination. As scheduled mortgage payments are made monthly, we price American continuous installment options to estimate the values of mortgage default and prepayment.

4.4 Theoretical Model

A mortgage termination option is analogous to an installment option with a straddle or strangle like payoff, as borrowers continuing to make scheduled mortgage payments are effectively keeping mortgage termination options alive until obligation denial or prepayment occur. An American chooser option consists of a right to choose or abandon an American call on an asset or an American put on the same asset, where the strike price and expiry date of an American call and put are not necessarily the same. A special case of an American chooser option is when the expiry date for the American chooser option coincides with the expiry date of the underlying options. In this case the chooser is identical

Figure 4.1: Payoff of American Continuous Installment Option with Straddle like Payoff



Note: The graph describes the payoff of straddle option (long positions of call and put options) which is the same as the payoff of chooser option. F_t and G_t are lower and upper critical property prices, K_t is strike price. However, an American continuous installment option is not identical to a chooser option, as in a chooser the option holder can separate the call from the put once he makes the decision. For an installment option, we cannot separate call and put.

to self-closing American straddle (Detemple and Emmerling (2009[56]), Qiu and Mitra (2018[140])). The option analogy of early mortgage termination is similar to this special case of American chooser option but the difference is that installment option can shift its maturity but American chooser option fix its maturity. Comparing with general chooser options, an installment option with a straddle like payoff captures the interaction between put and call options throughout the maturity but a general chooser option abandons either put or call once the option holder chooses to keep put or call before or at the maturity of the chooser option (there are no way to change after making the decision). Therefore, we conclude that early mortgage termination should be modelled as an installment option with a straddle or strangle like payoff (Figure 4.1) - i.e. long obligation denial (put) and prepayment (call) options - instead of American chooser option.[5]

We develop the theoretical model to price installment put options for obligation denial, installment call options for prepayment, and installment options with straddle or strangle like payoff (considering both put and call options). If we consider execution costs for each type of early mortgage termination options, we

[5] Installment options and chooser options are different and we cannot combine them together.

can also add the execution costs to strike prices of each type of option (this makes strike prices of each type of option different) and compute net option values.

Default as American continuous installment put option
A defaulting borrower surrenders the collateral and does not repay the remaining mortgage balance until maturity. Epperson et al. (1985[65]) model a mortgage as a compound of European put options. However, we argue that an American continuous installment put option is more appropriate to describe the decision to default because of a better match in the decision paths of payments when prepayment is ignored. Option values represent the gross benefit a borrower's gain by defaulting. Since significant implicit opportunity costs driven by inaccessibility of new borrowing after bankruptcy cannot be ignored, we further compute the net benefit by adding bankruptcy costs to the strike price of the underlying put option. In our analogy, borrowers are regarded as holders of American continuous installment put options since mortgage origination. When borrowers make scheduled mortgage payments, they keep the option alive. Otherwise, the option ceases to exist if they default once property values drop below the outstanding loan balance. They then exercise the option, making mortgage default occur.

Prepayment as American continuous installment call option
Similar to default, borrowers are regarded as holders of American continuous installment call options since mortgage origination while default is ignored. At every mortgage payment date, borrowers decide whether they should make the mortgage payment (i.e. installment) or fully prepay (i.e. exercise the call option), and the exercise price depends on the remaining mortgage balance. In addition, another incentive for full prepayment is the reduction of interest expenses. However, we assume that volatility in interest rates may not significantly affect the mortgage option; therefore we do not set the criteria of interest rate movement to estimate the value of full prepayment options in a one-dimensional model. We also build a two-dimensional model with a stochastic interest rate process and then compare the results to verify our assumptions on volatility of interest rates. In this case, execution costs consist of a prepayment penalty and net benefits are computed as option values after adding the prepayment penalty to the exercise price.

4.5 The Setup of Simulation

We conduct Monte Carlo simulations to price early mortgage termination options which are analogous to American continuous installment options, with a straddle like payoff if strike prices of put and call options are the same, and strangle like payoff when strike prices of put and call options are different. We separately price mortgage default and prepayment and then compare with a case which jointly considers all types of early termination options. The simulation setup involves numerous steps including risk-free discounting, creating property and interest rate processes (for two-dimensional model), setting up mortgage terms, computing early exercise and stopping boundaries for installment options, estimating execution costs etc.

4.5.1 Risk free discounting

Hull (2012 [106]) mentions that Treasury yields are artificially low and many financial institutions refer to overnight indexed swap rates and treat them as risk free rates. Thus, we follow the norm and base our analysis on overnight indexed swap rates as the risk free rate to discount the expected payoff of each option.

4.5.2 Property price process under risk neutral measure

We set up the log normal process for property prices under risk neutral measure (equation 4.1). The volatility of real estate prices is determined by property supply elasticities (SE) where *con* is a constant term based on historic volatility.

$$dp = (\mu_p \times p)dt + (\sigma_p \times p)dW_p \quad (4.1)$$

$$\mu_p = r - q \quad (4.2)$$

$$\sigma_p = con \times e^{(1-SE)} \quad (4.3)$$

μ_p : Drift on p
σ_p : Volatility of p
r: Risk free rate
q: Rental yield (i.e. service flow rate)
W_p : W-Wiener process of p under risk neutral measure

4.5.3 Interest rate process under risk neutral measure

For the two-dimensional model, an interest rate (r_t) is assumed to be a mean reverting stochastic process with a non-negative boundary, as developed by Cox, Ingersoll and Ross (1985 [51]):

$$dr = \gamma_r \cdot (\mu_r - r)dt + \sigma_r \sqrt{r} dW_r \tag{4.4}$$

γ_r : Speed of reversion of r
μ_r : Drift on r
σ_r : Volatility of r
W_r : W-Wiener process of r under risk neutral measure

We also assume that real estate prices correlate with interest rates, where $\rho dt = dW_p dW_r$ and ρ is the correlation coefficient.

4.5.4 Deterministic mortgage terms

Assuming that a fixed-rate constant payment mortgage is originated, the initial loan size (L_0), fixed monthly mortgage payments (M) and unpaid principal on payment date j (U_j) can be computed as follows:

$$L_0 = LTV_0 \times p_0 \tag{4.5}$$

$$M = L_0 \cdot \frac{h_m(1+h_m)^n}{(1+h_m)^n - 1} \tag{4.6}$$

with

$$L_0 = M \sum_{i=1}^{n} \frac{1}{(1+h_m)^i}$$

$$U_j = (1+h_m)U_{j-1} - M = M(\sum_{i=1}^{n}(1+h_m)^{j-i} - \frac{(1+h_m)^j - 1}{h}) \tag{4.7}$$

where LTV_0 is the initial LTV ratio, p_0 the initial property value, h_m the monthly fixed rate and n represents the number of amortization periods expressed in months.

Besides constant payment mortgages, we also analyze interest-only mortgages and constant amortization mortgages with intermediate balloon payments.

4.5.5 Valuing American continuous installment call options with early exercise and stopping boundaries

Prepayment is analogous to American continuous installment call options. We price prepayment by computing American continuous installment call options where early exercise and stopping boundaries are considered. Referring to Ciurlia and Roko (2005[48]), we denote lower critical property price, upper critical property price and the initial premium of American continuous installment call options as A_t, B_t and CAL(p_t,t;x) respectively. For each time t, there exists A_t below which it is beneficial to terminate mortgage payments by stopping the option contract and B_t above which it is optimal to early exercise the prepayment option. The initial premium function satisfies the inhomogeneous Black Scholes PDE in the continuation region as follow.

$$\frac{\partial CAL(p_t,t;x)}{\partial t}+\mu_p p_t\frac{\partial CAL(p_t,t;x)}{\partial p}+\frac{1}{2}\sigma_p^2 p_t^2\frac{\partial^2 CAL(p_t,t;x)}{\partial p^2}-rCAL(p_t,t;x)=x \tag{4.8}$$

It is subject to the following terminal and boundary conditions.

$$CAL(p_T,T;x) = 0 \tag{4.9}$$

$$\lim_{p_t\downarrow A_t} CAL(p_t,t;x) = 0 \tag{4.10}$$

$$\lim_{p_t\downarrow A_t} \frac{\partial CAL(p_t,t;x)}{\partial p} = 0 \tag{4.11}$$

$$\lim_{p_t\uparrow B_t} CAL(p_t,t;x) = B_t - K_t \tag{4.12}$$

$$\lim_{p_t\uparrow B_t} \frac{\partial CAL(p_t,t;x)}{\partial p} = 1 \tag{4.13}$$

If we price the option for CPM, at maturity the value of call option is zero. We apply a value matching condition such as Newton method to compute early exercise and stopping boundaries.

4.5.6 Valuing American continuous installment put options with early exercise and stopping boundaries

Denial obligation is analogous to American continuous installment put options. To price denial obligation, we follow the valuation of American continuous installment put options. Referring to Ciurlia and Roko (2005[48]), there are stopping and early exercise boundaries which are the time paths of lower and upper critical property prices C_t and D_t and divide the domain into a stopping region, a continuation region and an exercise region. The initial premium function of the American continuous installment put is denoted as PUT(p_t,t;x) where p is property price and x is continuous installment rate (i.e. M/L_0). The function satisfies the inhomogeneous Black Scholes PDE in the continuation region.

$$\frac{\partial PUT(p_t,t;x)}{\partial t}+\mu_p p_t\frac{\partial PUT(p_t,t;x)}{\partial p}+\frac{1}{2}\sigma_p^2 p_t^2\frac{\partial^2 PUT(p_t,t;x)}{\partial p^2}-rPUT(p_t,t;x)=x \tag{4.14}$$

It is subject to the following terminal and boundary conditions.

$$PUT(p_T,T;x) = 0 \tag{4.15}$$

$$\lim_{p_t\downarrow C_t} PUT(p_t,t;x) = K_t - C_t \tag{4.16}$$

$$\lim_{p_t\downarrow C_t} \frac{\partial PUT(p_t,t;x)}{\partial p} = -1 \tag{4.17}$$

$$\lim_{p_t\uparrow D_t} PUT(p_t,t;x) = 0 \tag{4.18}$$

$$\lim_{p_t\uparrow D_t} \frac{\partial PUT(p_t,t;x)}{\partial p} = 0 \tag{4.19}$$

We should note that the put option on CPM at terminal T is worthless as the mortgage is fully repaid. Same with prepayment, we apply value matching boundary condition such as Newton method to compute early exercise and stopping boundaries in Monte Carlo simulation.

4.5.7 Valuing American continuous installment options with early exercise and stopping boundaries

Early mortgage termination involves the options to deny or prepay and it is analogous to an American continuous installment option embedded straddle (if strike prices of underlying put and call options are the same) or strangle (if strike prices are different) payoff. In fact, we can treat the option as a call option (prepayment) where the denial feature (stopping payments at a lower boundary) acts as a put option (default). To price early mortgage termination, we follow the valuation of American continuous installment options. Referring to Ciurlia and Roko (2005 [48]), early exercise and stopping boundaries represent the time paths of lower and upper critical property prices F_t and G_t and they divide the domain into an exercise region, a continuation region and a stopping region. The lower critical property prices can indicate the maximum amount of negative equity that is tolerable before defaulting. The upper critical property prices can reflect the minimum of property values that trigger prepayment. The initial premium function of the American continuous installment option is denoted as V(p_t,t;x) where p is property price and x is the continuous installment rate (i.e. M/L_0 where M is mortgage payment and this payment relative to original mortgage balance proxies the installment rate). The function satisfies the inhomogeneous Black Scholes PDE in the continuation region.

$$\frac{\partial V(p_t,t;x)}{\partial t} + \mu_p p_t \frac{\partial V(p_t,t;x)}{\partial p} + \frac{1}{2}\sigma_p^2 p_t^2 \frac{\partial^2 V(p_t,t;x)}{\partial p^2} - rV(p_t,t;x) = x \quad (4.20)$$

It is subject to the following terminal and boundary conditions:

$$V(p_T,T;x) = 0 \quad (4.21)$$

$$\lim_{p_t \downarrow F_t} V(p_t,t;x) = K_t - F_t \quad (4.22)$$

$$\lim_{p_t \downarrow F_t} \frac{\partial V(p_t,t;x)}{\partial p} = -1 \quad (4.23)$$

$$\lim_{p_t \uparrow G_t} V(p_t,t;x) = G_t - K_t \quad (4.24)$$

$$\lim_{p_t \uparrow G_t} \frac{\partial V(p_t,t;x)}{\partial p} = 1 \quad (4.25)$$

At maturity, the constant payment mortgage (CPM) is fully repaid and options are worthless; on the other hand, for the interest only mortgage (IOM), the boundary conditions will look different (i.e. $V_T = max(p_T - (L_0 + Interest_T), 0)$). For CPM, the strike price K_t is time varying as repayments at time t are considered. For IOM, strike prices remain unchanged at the original mortgage principal. Furthermore, if we consider execution costs (bankruptcy cost and prepayment penalty), these will be added to the strike price and, therefore, call and put options will show different strike prices. We apply value matching boundary conditions via the Newton method to compute early exercise and stopping boundaries in the Monte Carlo simulation.

The payoff of American continuous installment option is straddle like and looks similar to a chooser option payoff. At the same time, an American continuous installment option is not identical to a chooser option, as in a chooser the option holder can separate the call from the put once he makes the decision. In our case however, we are unable to separate call and put in the American continuous installment option.

4.5.8 Option valuation with least squares Monte Carlo method

Longstaff and Schwartz (2001 [121]) introduce the least squares Monte Carlo method to price American options by estimating the continuation values and subsequently early exercise cash flow. Ciurlia and Roko (2005[48]) extend the method to accommodate the pricing of the American continuous installment options. The continuation value of American continuous installment options (y_i^j) is $e^{-r\Delta t}V_{i+1}^j(p_{i+1}^j) - \frac{x}{r}(1-e^{-r\Delta t})$, where i and j are time step and number of replication, $V_{i+1}^j(p_{i+1}^j) = max\{f(p_{i+1}^j), E_{i+1}(e^{-r\Delta t}V_{i+2}^j(p_{i+2}^j)|p_{i+1}^j)\}$, f represents the payoff function and $\frac{x}{r}(1-e^{-r\Delta t})$ is the present value of installment premia paid up to the time of termination (which is one of components of the solutions to the free boundary value problems related to equation 4.20).
Ciurlia and Roko (2005) separate the set of replication paths into two subsets J_i^E (paths in the money) and J_i^S (paths out of the money), but in our study we need to combine subsets of put and call options. We apply a least squares regression to estimate the conditional expectation and set up decision rules for early exercise at time i (i.e. $f(p_i^j) \geq \hat{y_i}^j$ where j in J_i^E) and stopping the option (i.e. $\hat{y_i}^j \leq 0$ where j in J_i^S). The conditional expectation is estimated separately on different subsets. The initial value of the continuous installment option conditional on p_i^j is summarized as follows:

$$V_i^j(p_i^j) = \begin{cases} max\{f(p_i^j), (E_i(e^{-r\Delta t}V_{i+1}^j(p_{i+1}^j)|p_i^j) - \frac{x}{r}(1-e^{-r\Delta t}))\} & \text{if } j \in J_i^E \\ max\{0, (E_i(e^{-r\Delta t}V_{i+1}^j(p_{i+1}^j)|p_i^j) - \frac{x}{r}(1-e^{-r\Delta t}))\} & \text{if } j \in J_i^S \end{cases}$$

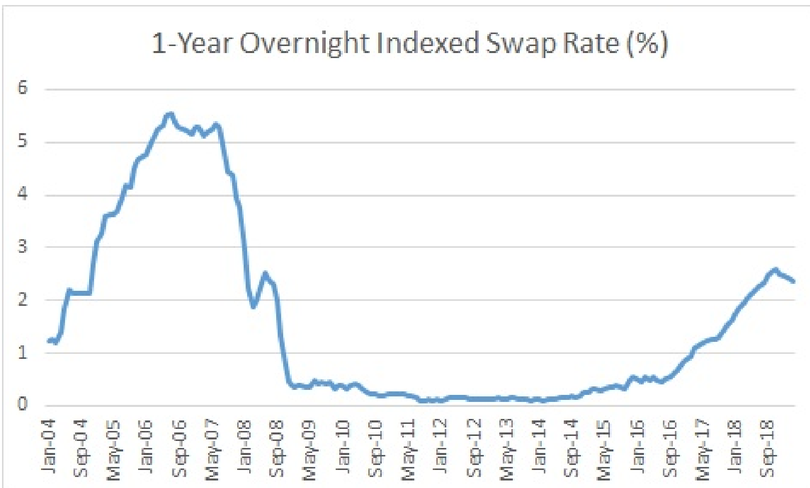
4.6 Parameterization

We model interest rate and property price processes, as well as mortgage terms. Subsequently, we estimate execution costs and add them to the strike price of underlying options (default and prepayment) to compute gross and net option values under different assumptions.

4.6.1 Interest Rate Process

We collect 1-year overnight indexed swap rates' data between January 2004 and December 2018 from the Thomson Reuters and estimate average and standard deviation values, which are used in the Cox, Ingersoll and Ross model (1985[51]) respectively as the drift and volatility terms. As real world density is different from risk neutral density, risk transformation by adjusting the drift of the stochastic process is needed (Giordano and Siciliano 2015 [85]). Theoretically, Radon-Nikodym derivative and Girsanov Theorem are applied to transform real world probability to risk neutral probability. Due to a long period of unchanged target rates by the Fed since the Global Financial Crisis and cautious long-term monetary policies, we assume that interest rates move steadily, with mean reversion of rates at moderate speed (0.2).

Figure 4.2: Overnight Indexed Swap Rate



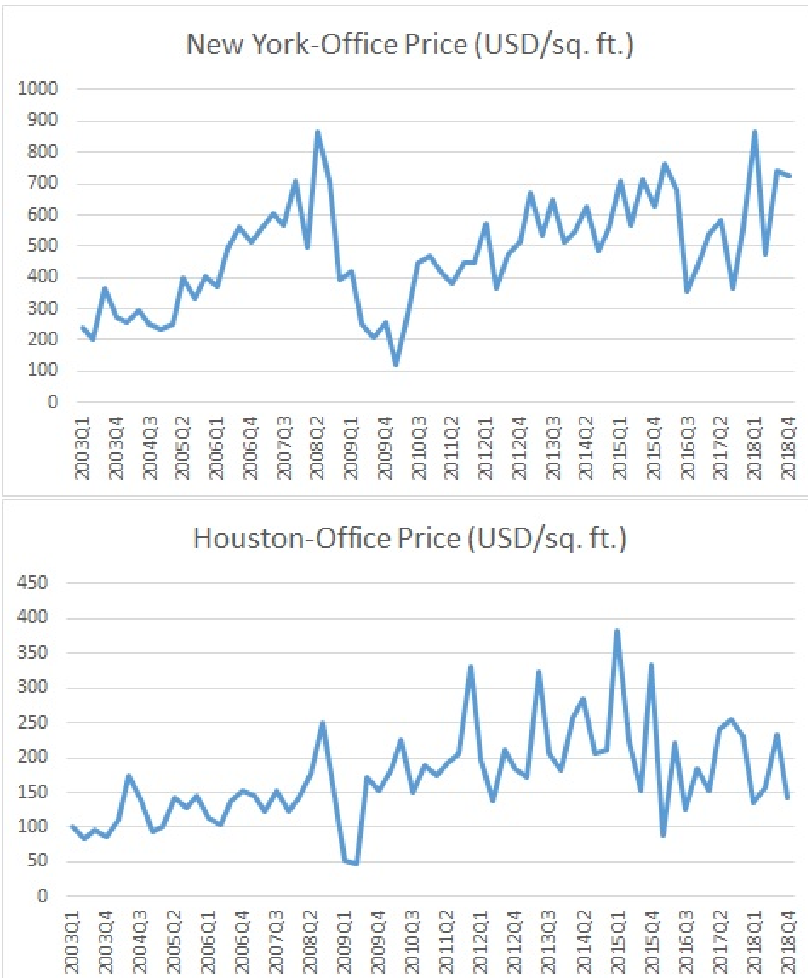
Source: Thomson Reuters

4.6.2 Property Price Process

As our model analyzes the early termination of commercial mortgages, we use average office values and rental yields (akin to dividend yields of stocks) among 42 metropolitan statistical areas (MSA hereafter) from the 2nd quarter 1993 to the 4th quarter 2015 (source: CBRE Econometric Advisors, a US consultancy firm with a proprietary dataset of real estate fundamental metrics across MSAs). Similar to interest rates, risk transformation is needed for building the stochastic process under the risk neutral measure with real world histories by adjusting the drift of the process (Giordano and Siciliano 2015 [85]). Following Hull (2012 [106]), the drift links to the risk free interest rate in the risk neutral world. We apply a log normal model to the property price process. The volatility of property prices is determined by property supply elasticity, thus we estimate office supply elasticities by error correction models for 42 MSAs in Chapter Three. The volatility formula also involves a constant term computed as the historical average volatility.

We show office prices in New York City (i.e. perfectly supply inelastic) and Houston (i.e. less inelastic) in Figure 4.3 and find that New York City has greatest fluctuation due to the Global Financial Crisis (around -90% in New York City vs -80% in Houston).

Figure 4.3: Office Prices in the US Cities



Note: Greatest fluctuation in office prices are found in New York City where supply is perfectly inelastic. (Source: CBRE Econometric Advisor)

4.6.3 Mortgage Terms

Our model is applicable to any type of mortgages. In our study, we compare results for two common mortgage contracts with 10 year maturity generated by one dimensional model: constant payment mortgage (CPM) and interest only mortgages (IOM). When we apply a two dimensional model, we compare simulation results for CPM and constant amortization mortgage with an intermediate balloon payment of 50% of original principal (at the fifth year). Assuming an initial loan-to-value (LTV) ratio of 50%, we normalize the property values at $1. We restrict our analysis to 42 MSAs because supply elasticities of office markets are only available for this sample, which covers 50% of the entire US population and 60% of the US population in office employment.

4.6.4 Execution Costs

Bankruptcy Costs. Overall bankruptcy costs could be estimated by the opportunity cost of losing future capital returns during the bankruptcy period caused by the lack of access to funds. These are implicit costs that borrowers have to bear. We analyze about 1,000 bankruptcy records provided in UCLA-Lo Pucki Bankruptcy Research Database since October 1979 and estimate bankruptcy duration as the length of period from bankruptcy filing to the confirmation of effective plans. On average, bankruptcy last for 18 months. We proxy the post-trough return using the total return in office markets for the 42 MSAs sourced from CBRE Econometric Advisors. As we observe a trough in 2009, we take average annual returns from 2010 to 2011 as post-trough returns for the 18 months to estimate bankruptcy costs.

Prepayment Penalty. Based on over 10,000 securitized mortgages containing covenants of prepayment penalty sourced from Bloomberg, we find lenders mostly charging at a rate of 9% for 9.5 months. In our model, we set up the penalty with this rate on the remaining unpaid principal balance.

Table 4.1 summarizes the parameter values used in our baseline case.

Table 4.1: Baseline Parameters

Description	**Parameter**	**Initial**	μ	σ	γ
Interest Rates	r	0.04	0.05	0.2	0.2
Property Value	p	1	μ_r-q	$e^{(1-SE)} * 0.1$	
Rental Yield	q	0.03			
Supply Elasticity	SE	0.1325			
Correlation between Interest Rate and Property Value	ρ	+0.25			
Mortgage Terms					
Initial Loan-to-Value Ratio	LTV_0	0.5			
Maturity (Months)	n	120			
Execution Costs					
Bankruptcy Duration (Months)		17.685			
Post-Trough Return		0.03			
Prepayment Penalty Rate		0.09			
Penalty Period (Months)		9.5			

Notes:
μ: mean; σ: standard deviation; γ: reverting speed.
We set up two stochastic processes: interest rates and property values. All types of mortgages (CPM, IOM, CAM with intermediate balloon payments) are assumed to have maturity of 10 year and LTV of 50%. Bankruptcy duration and post-trough return are used to estimate bankruptcy costs. Prepayment penalty rate and penalty period are used to estimate prepayment penalty.

4.7 Simulation Results and Analysis

4.7.1 Comparison of Simple European Option Values with Analytic Solution

Before valuing American installment options, we construct simple European options of mortgage default (put), prepayment(call) and straddle (i.e. long positions of put and call) and simulate their values by Monte Carlo method and compare them with analytic solutions obtained with a Black and Scholes formula. Table 4.2 summarizes the comparison. We conduct several simulations with increasing number of simulation paths from 100 to 10,000. Referring to the simulations with 10,000 paths for CPM, estimates of European put option (mortgage default) equal zero, same as for the analytic solution obtained with a Black and Scholes formula. The European call option (prepayment) also shows simulated values similar to the analytic solution (i.e. 0.05% deviation). We draw the same conclusion on simulated straddle option values (joint default and prepayment). For IOM, deviations of simulated values from analytic solutions of all three types of European options are greater than the deviations for CPM.

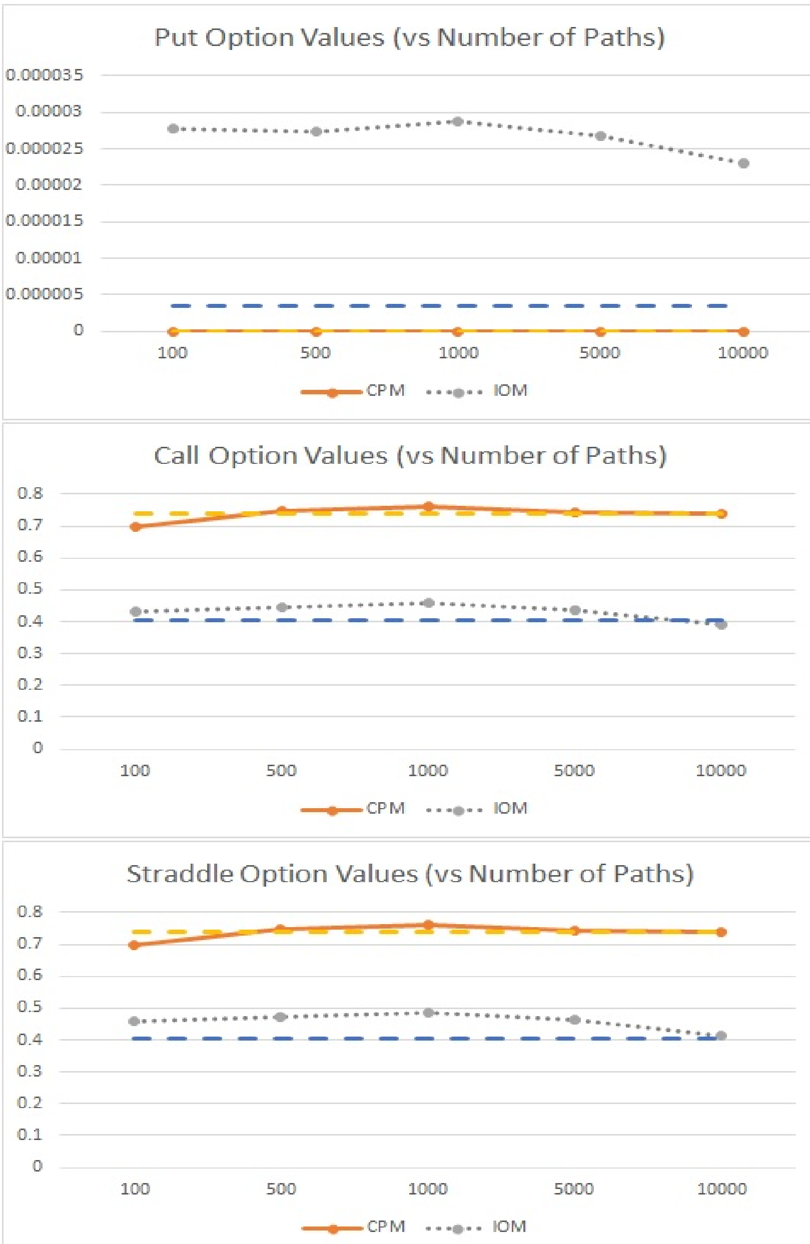
Increasing the number of simulation paths allows the school to improve the accuracy of Monte Carlo simulation in general, even if processing times increase at the same time. We present the graphs showing the relationship between simulated option values and number of simulation paths in Figure 4.4. We confirm that the simulated option prices generally converge to the values computed with the Black and Scholes formula.

Table 4.2: European Options (Comparison of Monte Carlo Simulation with Analytical Solutions)

Option	CPM		IOM	
	MC(n=10000)	Black Scholes	MC(n=10000)	Black Scholes
Put (Default)	0	0	2.3×10^{-5}	3.45×10^{-6}
Call (Prepayment)	0.7369	0.7373	0.389	0.4057
Straddle (Joint Default and Prepayment)	0.7369	0.7373	0.389	0.4057

Notes:
We check the convergence of Monte Carlo simulation values for each type of option. We increase number of paths from 100 to 10,000. For simulation with 10,000 paths, the Monte Carlo simulation values are close to the values computed with Black & Scholes formula. Therefore, we conclude that simulation values are convergent to the analytical solutions.

Figure 4.4: European Option Values vs Number of Simulation Paths



Note: Values of each type of option (put, call, and straddle) converge to analytical solutions (dash lines) by increasing number of simulation paths.

4.7.2 Valuing Mortgage Default Options When Prepayment Is Ignored

We ignore prepayment and then value mortgage default options as American continuous installment put options. Under the baseline scenarios in the one dimensional model, mortgage default options for CPM and IOM are worth \$0.5401 and \$0.0288 respectively. After considering the execution costs (i.e. bankruptcy) by adding it to the strike price of underlying options, net default options for CPM and IOM are valued at \$0.1051 and \$0.0277. We price American installment options by modifying the least squares Monte Carlo simulation introduced by Longstaff and Schwartz (2001[121]) to involve estimations of continuation values, early exercise and stopping boundaries. To estimate continuation values (the formula is shown in the section of the setup of simulation), we regress discounted immediate exercise payoff minus discounted installments on Laguerre polynomial functions of property prices as follows:

$$L_0(p) = e^{-p/2} \quad (4.26)$$

$$L_1(p) = e^{-p/2}(1-p) \quad (4.27)$$

$$L_2(p) = e^{-p/2}(1-2p+\frac{p^2}{2}) \quad (4.28)$$

We compare continuation values with immediate exercise payoffs to decide if it is optimal to immediately exercise mortgage default options. The comparison implies that for the majority of 1,000 paths immediate exercises occur for CPMs, but less likelihood of immediate exercise default options for IOMs is seen. Early exercise and stopping boundaries can indicate the maximum amount of negative equity that is tolerable before missing a payment. For CPMs, as the remaining mortgage balance decreases with time, the maximum amount of tolerable negative equity also decreases. The reduced equity values range from 0.3% to 49% of an initial property value and after deducting the remaining mortgage principal, the maximum values of tolerable net negative equity range from 0.0006% to 0.2% of an initial property value. For IOMs, as the outstanding loan balance does not change over time, the maximum amount of tolerable negative equity remains unchanged over time and it is valued at 50% of the initial property value. As CPM borrowers have less tolerance to negative equity than IOM borrowers, they will be more likely to default. Therefore, the value of mortgage default options for CPMs should be higher than for IOMs.

4.7.3 Valuing Prepayment Options When Mortgage Default Is Ignored

We value prepayment options as American continuous installment call options while mortgage default is ignored. Under the baseline scenarios in the one dimensional model, prepayment options for CPMs and IOMs are worth \$2.0664 and \$1.3178 respectively. After considering the execution costs added to the strike price of underlying options, net prepayment options for CPMs and IOMs are valued at \$2.0311 and \$1.2858. We also estimate continuation values, early exercise and stopping boundaries for prepayment options and similarly for mortgage default. We then compare continuation values with immediate exercise payoffs to decide the optimality of an immediate prepayment option exercise.

We find that the majority of simulation paths suggest immediate exercises. The early exercise premia for CPMs and IOMs are approximately worth at \$1.3 and \$0.9 respectively.

To understand the minimum equity amount that triggers refinancing, we compute early exercise and stopping boundaries of prepayment options. We find that for CPMs the threshold level varies with the outstanding loan balance and the minimum net equity amount ranges from 100% to 150% of the initial property value. For IOMs, the minimum net equity amount is valued at 150% of the initial property value. In other words, the property value of the collateral reaches the minimum level of \$1.5 (normalized initial property value at \$1) and subsequently the IOM borrower decides to refinance. We discuss the impact of interest rate movements on the threshold level of equity that triggers refinancing using a two-dimensional model in the next section.

4.7.4 Valuing Early Termination Options: Joint Mortgage Default and Prepayment Options

Joint mortgage default and prepayment options are analogous to American continuous installment options with a straddle or strangle payoff. Under the baseline scenario in a one dimensional model, joint options for CPM and IOM are valued at \$2.6065 and \$1.3466 respectively. Considering execution costs, the net joint options for CPMs and IOMs are worth at \$2.0833 and \$1.3136 respectively. The strategic boundaries of joint options come from the early exercise and stopping boundaries of mortgage default and prepayment options by taking the maximum of two kinds of boundaries. As discussed in the previous section, stopping payment at the lower boundary for a joint option is the same as the stopping boundary showing the path of lower critical property prices for an one-sided de-

fault put option. The early exercise boundary for a joint option is the same as the path of upper critical property prices for an one-sided prepayment call option. We conclude that the maximum amount of tolerable negative equity based on the joint options is the same as the one driven by mortgage default one-sided options. Moreover, the minimum equity amount that triggers refinancing based on joint options is also the same as the threshold for prepayment one-sided options.
The values of early termination options are the sum of values of mortgage default and prepayment options. Early termination options (joint mortgage default and prepayment options) gain benefits by obtaining the rights to select between mortgage default and prepayment and to replicate payoff of both options. Thus, the benefits can be maximized in different scenarios. When both options are considered jointly, this straddle or strangle strategy can help to capture the gains from large movements of the underlying property prices although the direction of the movement is uncertain and not known apriori. We compare the values of mortgage default and prepayment options and exercise one option where the payoff values are highest. Prepayment negates the value of default, and ceases to be of value when default occurs. On the other hand, mortgage default also negates the prepayment value and its value turns to zero when prepayment occurs. In other words, if the prepayment value is greater than the default value, prepayment is more likely to occur, and an inverse relationship between prepayment and mortgage default value exists.

4.7.5 One Dimensional vs Two Dimensional Model

As real estate prices are stochastic, we develop a two dimensional model to capture stochastic interest rates. To do this, we setup a loop to replicate the steps generating correlated stochastic variables by using the Cholesky decomposition method (Glasserman 2004 [89]) and then simulating the interest rate (Cox, Ingersoll and Ross model) and property price process (geometric Brownian motion) with correlated stochastic variables. Simulated paths are input to another loop to value early mortgage termination options. Table 4.3 summarizes the values of mortgage default (one-sided when prepayment is ignored), prepayment (one-sided when default is ignored) and early termination options (considering both default and prepayment) in different scenarios of interest rate parameters. In general, the results generated by the two dimensional model are similar to those from the one dimensional model for CPMs. We also evaluate early termination options for a constant amortization mortgage (CAM) with an intermediate balloon payment and note that, after deducting execution costs, one-sided mortgage

default options for IOMs are worth zero in every scenario.
When the volatility of interest rates decreases from 0.4 to 0.2, changes in values of mortgage default and prepayment and early termination options occur in different directions. For the majority of scenarios without considering execution costs for CPMs, a positive relationship between the volatility of interest rates and values of mortgage default options is found. If we consider execution costs, this positive relationship is even more significant and clearer. We also find a positive relationship with prepayment option values for CPMs but cannot draw a clear conclusion for CAMs with an intermediate balloon payment. If interest rates are less volatile, the likelihood of prepayment for CPMs decreases. In addition, hazy relationships between volatility of interest rates and early mortgage termination options (joint default and prepayment options) for CPMs and CAMs with an intermediate balloon payment are obtained.
Regarding the relationship between speed of reversion in interest rates and early termination options (both one-sided and joint options), we find that speed of reversion in interest rates negatively correlates with the value of one-sided options for the majority of scenarios without including execution costs for CAMs with an intermediate balloon payment, but unclear relationships are found for joint options. However, the deduction of execution costs makes results stronger and it confirms a negative relationship for joint options. For CPMs we cannot find a consistent relationship for one-sided and joint options, whatever type of execution costs are considered.
We also conduct a scenario analysis on the correlation between property prices and interest rates. However, nonlinear relationships between the correlation and early mortgage termination options for the majority of scenarios are found. The striking feature lies in the linear relationship between volatility of interest rates = 0.4 and speed of reversion = 0.4. Without the inclusion of execution costs, increases in correlation (-0.25 to +0.25) increase values of default, prepayment and early mortgage termination options (strangle options) for CPMs by 62%, 47% and 1% respectively, while for CAMs with an intermediate balloon payment, values of default, prepayment and early mortgage termination options are increased by 55%, 41% and 3% respectively. Including execution costs, values of default and prepayment as well as early mortgage termination options increase by respectively 22%, 47% and 34% for CPMs, while values of prepayment and joint early termination options increase by 40% for CAMs with an intermediate balloon payment.
Overall, there are almost no clearcut linear relationships between interest rate related parameters and early mortgage termination options.

Table 4.3: Scenario Analysis on Early Mortgage Termination by Using Two Dimensional Model

σ_r	γ_r	ρ	**Default**		**Prepayment**		**Strangle**	
			CPM	CAM	CPM	CAM	CPM	CAM
Without Inclusion of Execution Costs								
0.2	0.2	-0.25	0.540	0.317	2.207	1.987	2.747	2.304
0.4	0.2	-0.25	0.347	0.216	1.515	1.431	2.759	2.289
0.2	0.4	-0.25	0.313	0.193	1.409	1.362	2.758	2.311
0.4	0.4	-0.25	0.337	0.208	1.517	1.424	2.745	2.263
0.2	0.2	0	0.320	0.197	1.433	1.394	2.740	2.296
0.4	0.2	0	0.538	0.316	1.485	1.391	2.738	2.268
0.2	0.4	0	0.322	0.200	2.209	1.988	2.751	2.307
0.4	0.4	0	0.346	0.216	1.547	1.439	2.755	2.286
0.2	0.2	+0.25	0.540	0.317	2.208	1.988	2.748	2.305
0.4	0.2	+0.25	0.343	0.214	2.229	2.007	2.776	2.330
0.2	0.4	+0.25	0.329	0.204	1.441	1.382	2.749	2.304
0.4	0.4	+0.25	0.545	0.322	2.227	2.006	2.773	2.327
With Inclusion of Execution Costs								
0.2	0.2	-0.25	0.056	0	2.172	1.952	2.228	1.952
0.4	0.2	-0.25	0.062	0	1.493	1.410	1.729	1.410
0.2	0.4	-0.25	0.047	0	1.393	1.344	1.800	1.344
0.4	0.4	-0.25	0.061	0	1.495	1.405	1.691	1.405
0.2	0.2	0	0.045	0	1.416	1.374	1.765	1.374
0.4	0.2	0	0.059	0	1.468	1.373	1.692	1.373
0.2	0.4	0	0.057	0	2.173	1.952	2.231	1.952
0.4	0.4	0	0.063	0	1.528	1.419	1.745	1.419
0.2	0.2	+0.25	0.056	0	2.173	1.952	2.228	1.952
0.4	0.2	+0.25	0.074	0	2.194	1.972	2.268	1.972
0.2	0.4	+0.25	0.059	0	1.423	1.362	1.799	1.362
0.4	0.4	+0.25	0.074	0	2.192	1.970	2.266	1.970

Note: For each scenario, we simulate 1000 paths. We set up different cases with volatility of interest rates (σ_r=0.2 or 0.4), speed of reversion (γ_r=0.2 or 0.4) and correlation between interest rates and property values (ρ= -0.25, 0 or +0.25). For cases without considering execution costs (bankruptcy costs for mortgage default and prepayment penalties for prepayment), joint default and prepayment options are analogous to straddle which is a special example of strangle. Regarding cases considering execution costs, joint options are analogous to strangle which have long positions for both default and prepayment options. Other parameters in the model are same as the setup of the baseline scenario.

4.7.6 Impact of Balloon Payments on Early Termination Options

Kau et al. (1987 [112] and 1990 [113]) price a commercial mortgage, which has a 30-year amortization schedule with a 15-year balloon payment. In our study, we model the 10-year constant amortization mortgage with an intermediate balloon payment of 50% of original mortgage principal. Compared to CPMs, the value of early termination options embedded in CAMs with an intermediate balloon payment are lower for any type of execution costs. In general, prepayment values are higher than default values and this finding is consistent with the overall simulation results presented in Kau et al. (1990 [113]).

4.7.7 Impact of Property Supply Constraints on Early Termination Options

Property supply constraints determine volatility of property prices. The more elastic the real estate supply is, the less volatile property prices are. We set up four scenarios of property supply constraints: perfectly inelastic (SE=0), inelastic (SE=0.5), unitary elastic (SE=1) and elastic (SE=2). Referring to Table 4.4, our simulation results are in line with theoretical expectations. When property supply is perfectly inelastic, option values for both CPMs and CAMs with an intermediate balloon payment are greater than those in less inelastic property supply markets. Comparing among three options (one-sided mortgage default, one-sided prepayment, and joint default and prepayment options), a decrease in one sided mortgage default option value is greatest by relaxing property supply constraints (i.e. increasing property supply elasticities) and the value turns to zero while property supply is elastic (i.e. SE=2). Thus, the likelihood of mortgage default is significantly reduced. Increasing property supply elasticities (SE from 0 to 2) also causes joint default and prepayment option values decrease by 28% for CPMs and 17% for CAMs with an intermediate balloon payment and hence lower overall probability of early mortgage termination. After including execution costs, net option values of mortgage default, prepayment and early mortgage termination (joint default and prepayment) for CPMs decrease by 100%, 10% and 13% respectively when property supply becomes more elastic (from 0 to 2). Decrements in option values for CAMs with an intermediate balloon payment are smaller than for CPMs except for one-sided mortgage default which is worth zero in each scenario. Results generated by our one and two dimensional models are consistent. Therefore, we conclude that controlling supply constraints could represent an alternative risk management tool to alter mortgage borrowers' decision which may reduce mortgage risks for lenders. Consequently, regulators may consider the preferences of differentiating capital requirements for banks lending in more or less constrained real estate markets.

Table 4.4: Impact of Property Supply Constraints on Early Mortgage Termination

SE	**Default**		**Prepayment**		**Strangle**	
	CPM	CAM	CPM	CAM	CPM	CAM
Without Inclusion of Execution Costs						
0	0.540	0.319	2.252	2.023	2.815	2.342
0.5	0.090	0.056	2.222	1.996	2.312	2.052
1	0.005	0.003	2.165	1.957	2.170	1.960
2	0	0	2.036	1.952	2.036	1.952
With Inclusion of Execution Costs						
0	0.052	0	2.217	1.988	2.292	1.988
0.5	0.011	0	2.187	1.961	2.198	1.961
1	0.0006	0	2.130	1.922	2.131	1.922
2	0	0	2.001	1.909	2.001	1.909

Note: For each scenario, we simulate 1000 paths by a two dimensional model. We set up four different levels of property supply elasticities (SE = 0, 0.5, 1 and 2) and compare values of early mortgage termination options. For cases without considering execution costs (bankruptcy costs for mortgage default and prepayment penalties for prepayment), joint default and prepayment options are analogous to straddle which is a special example of strangle. Regarding cases considering execution costs, joint options are analogous to strangle which have long positions for both default and prepayment options. Other parameters in the model are same as the setup of the baseline scenario.

4.8 Conclusion

We contribute to the research area of early mortgage termination by pricing installment options. We contribute to the existing literature in three ways. First, we revise the option analogy to price early mortgage termination and assimilate it to an American continuous installment option equipped with straddle or strangle payoff as options keep alive when scheduled mortgage payments as installments are made. Second, we include a property price process depending upon the supply constraints of the real estate market where the collateral is located. Third, we capture execution costs (i.e. bankruptcy costs for mortgage default and prepayment penalties for prepayment) in the option pricing model by adding them to the strike price of underlying options.

Without the inclusion of execution costs, prepayment options are more valuable than denial options for both CPMs and IOMs. Values of early termination options (joint mortgage default and prepayment options) are the sum of one sided options. This implies that a straddle strategy brings benefits by offering the right to select an option to exercise. When we include execution costs in strike prices of corresponding underlying options, prepayment options are still more valuable and values of early termination options are the sum of one-sided options for both CPMs and IOMs. We also find the maximum amount of tolerable negative equity which is valued at 50% of the initial property price and the minimum net equity amount that triggers prepayment at 150% (percentage of the original property price).

Finally, we illustrate that supply constraints play a key role in determining the option exercise. The option values of mortgage default, prepayment and early mortgage termination decrease by 100%, 10% and 28% for CPMs if underlying property markets become more elastic (i.e. supply elasticity increases from 0 to +2). The decrease is smaller for CAMs with an intermediate balloon payment than for CPMs. With the inclusion of execution costs, net option values also decrease with supply elasticities but the decrease in early termination option values (joint mortgage default and prepayment options) is less than when execution costs are excluded.

Overall, we argue that bank regulators should consider the proportion of bank lending granted to more or less supply constrained real estate markets. From a policy maker's point of view, the adoption of metrics of property supply elasticities for banks' mortgage portfolios could form part of the risk assessment and compliance process, where higher (lower) capital requirements are applied to banks with collateral in more (less) supply constrained markets. Finally, the existence of a significant exposure of the banking system may be risk managed by suggesting a temporary or more permanent relaxation of supply constraints within those areas, or at least by avoiding a tightening in correspondence of financial distress.

Chapter 5

Empirical Investigation of Borrowers' Strategic Choices

5.1 Abstract

Using a dataset of around 12,000 US office mortgages in 42 MSAs covering 60% of the US service labour force from 2001 to 2017, we shed light on the role played by supply constraints of underlying real estate markets on the exercise of mortgage termination options. Particularly, we empirically test the two-stage decision framework using a multinomial logit model for prepayment and denial options in the first stage and a logit model in the second stage for prepayment in cash vs defeasance and default vs mortgage restructuring. We find that MSAs with less restrictive supply constraints show a more frequent exercise of prepayment options, especially through defeasance rather than cash, but less frequent exercise of denial options. For partial prepayment, collateral assets in less supply constrained markets reduce the likelihood of an exercise. As a result a greater uncertainty present in supply inelastic real estate markets stimulates partial rather than full prepayment as borrowers act strategically by cashing in a fixed gain of the equity surplus in the partial prepayment, but decide to keep the option open on the remaining balance for potential further uplifts. Therefore, we argue that regulators need to monitor lending to supply constrained markets and policy makers should consider controlling property supply constraints as an alternative risk management tool to influence mortgage termination decisions.

5.2 Introduction

Over the last decade, we have witnessed a revolutionary shift in the nature of office space demand from individual offices to collaborative space based on several phenomena. Firstly, all major corporations started to adopt shared and open work space as well as work-from-home policies. Furthermore, smaller companies have been sharing office facilities and repetitive work is sometimes superseded by automation. These shifts often translate into negative demand shocks in office markets. As most office investment is funded with leverage, lenders, investors of commercial mortgage backed securities and policymakers are duly concerned about the borrower's exercise of denial options under those conditions. As of 2017, 16% of mortgages collateralized with office properties have defaulted and 4% were restructured. Moreover, recent long term quantitative easing measures promote extremely low interest rates and stimulate prepayment in cash and defeasance[1]. As a result, nearly 60% of commercial mortgages collateralized with office properties are prepaid in cash and 15% are defeased as of 2017.[2]

In Chapter Four, we present a theoretical model to price early mortgage termination options. Following from those insight, we hereby develop a two-stage theoretical model to price four early termination options grouped as two pairs of competing options with different triggering conditions: (a) default vs restructuring and (b) prepayment in cash vs defeasance. The theoretical model suggests that tightening collateral underlying property supply constraints increases values of early mortgage termination options and this represents our main research hypothesis in this work.

We provide an empirical evidence of the impact of several risk factors including property supply constraints on the likelihood of these four early mortgage termination options using a database of around $12,000$ commercial mortgages collateralized with office properties in the period of March 2001 to August 2017. Following the development of the two-stage theoretical model, we adopt a multinomial logit model in the first stage and a logit model in the second stage to estimate the probabilities of early mortgage termination options. We also examine the partial prepayment behaviour by adding an extra outcome in the first stage and a pair of competing options (curtailment[3] vs partial defeasance) in the second stage.

[1]Defeasance refers to a prepayment type where the borrower terminates the mortgage contract by transferring Treasury securities which replicate the cash flow structure of the relative commercial mortgage.

[2]Source: Trepp, leading provider of performance data on US securitised and unsecuritised mortgage loans.

[3]Curtailment refers to partial prepayment in cash

We find that default is more likely than restructuring and a cash settlement is more likely than defeasance. In the first stage, we show that mortgage rates, mortgage type (interest only mortgage, i.e. IOM), debt service coverage ratio (DSCR) and credit tenant lease significantly impact on the exercise of both prepayment and denial options. Consistent with previous theoretical findings, we emphasize the role of supply constraints of underlying real estate markets in this decision process, where one unit increase in property supply elasticities reduces the likelihood of denying obligations by 55% and raises the likelihood of prepayments more than three times. In the second stage, we show that an increase in property supply elasticities significantly lowers the probabilities of restructuring relative to mortgage default, but increases the probability of defeasance relative to prepayment in cash. Therefore, we find confirmation of the need for regulators to monitor the geographical composition of lending particularly in supply constrained real estate markets and for policymakers to consider managing the risk of mortgage termination options by relaxing/tightening supply constraints in underlying property markets.

To our knowledge this also represents the first empirical study on the partial prepayment behaviour, which is significantly affected by negative amortization rate, mortgage rate, mortgage type, cross collateralization, DSCR and property supply elasticities. Interestingly, an increase in property supply elasticities significantly reduces the likelihood of partial prepayment. Greater uncertainty in supply inelastic property markets lowers the appetite of borrowers to make a full prepayment as they prefer to partly keep the option of further market uplifts open by choosing to only partially prepay (with preference for curtailment).

This chapter is organized as follows: the next section provides a literature review related to the geographical variation of early mortgage termination options and the role played by property supply elasticity. Section 5.4 presents our conceptual framework, while section 5.5 includes a data description and outlines our empirical strategy and the two-stage logistic model framework. Sections 5.6 discusses the main results and reports robustness checks. Finally, we draw our conclusions in the last section.

5.3 Literature Review

The majority of empirical studies about early mortgage termination focus on mortgage default in the United States. However, only few studies note the geographical variation of default rates in commercial mortgage markets. Ciochetti et al. (2002)[44] gather commercial mortgage data in the period of 1974-1990 from an anonymous multiline insurance company and the Council of Real Estate Investment Fiduciaries and the American Council of Life Insurance. The regional variation in loan termination behaviour is examined with a proportional hazard model. Mortgages originated in the Southwest region exhibit the greatest default risk, while in contrast, the default probability in East North Central, Mideast and Pacific is the lowest. Yildirim (2008)[180] uses a combination of data sources (incl. WOTN, Trepp and American Council of Life Insurers foreclosure databases) to examine the default likelihood of CMBS loans by disentangling the probability of "long-term survivorship" and the timing of default occurrence within a logistic framework. The Southwest and Pacific regions show respectively the largest and lowest default probability. An et al. (2010)[18] acquire a CMBS loan panel dataset for the 1998-2007 period from Intex and use a hazard model with newly introduced factors (e.g. prepayment lock out and natural disaster) to examine the regional variation in default rates of CMBS loans. After controlling for the duration effect of default risk, hazard ratios suggest that East South Central, West South Central and East North Central have over 2 to 4 times higher default rates than Mid Atlantic. Default in East South Central is the highest, while in Pacific it is only half of that in Mid Atlantic. Furthermore, An et al. (2013)[16] emphasize the important role of both micro- and macro-location (e.g. zip-code level house price indices, MSA level commercial land price indices, county level unemployment rates) in explaining CMBS loan default. They obtain data for over 30,000 CMBS loans from Morningstar in the period between 1998 and 2012 and analyze the dataset by using a Cox proportional hazard model. Mortgage default is found to be highest in the Mountain, West South Central and East North Central regions. Tong (2014)[164] focuses on the role of property supply constraints on commercial mortgage default and adopts the linear probability model with interaction terms to analyze around 6,000 commercial mortgages collected from Bloomberg. She concludes that commercial mortgages collateralized by properties located in more severly supply constrained markets bear greater default risk. However, as supply elasticities by property types are not estimated with econometric models, results may not be reliable.

The geographical variation of prepayment risk in commercial mortgages is rarely investigated. Ciochetti et al. (2002)[44] and Ambrose and Sanders (2003)[15] employ competing risk models to simultaneously estimate default and prepayment risk by region. The former study finds the lowest prepayment rate in the Southwest region while the latter shows that mortgages on properties located in the mid-west are more likely to prepay relative to the western region.

Property supply constraints can account for geographical variation in the likelihood of early mortgage termination. In residential mortgage studies, the effects of property supply elasticities are investigated in depth using housing supply elasticities produced by Saiz (2010)[149] - see Adelino et al. (2014[3], 2016[2]), Alimov (2016[8]), Ambrose, Conklin and Yoshida (2016[13]), Bogin et al. (2017[31]), Chetty, Sandor and Szeidl (2017[40]), Dagher and Kazimov (2015[52]), Favara and Imbs (2015[69]), Han, Park and Pennacchi (2015[100]) and Saiz (2010[149])). As property supply is inelastic, higher property demand translates into mostly higher real estate prices rather than more construction. Moreover, real estate prices fall slower in supply inelastic cities compared to elastic cities if a negative demand shock is permanent. Therefore we can clearly establish a link between property supply elasticity and mortgage performance. An expansion of credit supply imposes greater effects of real estate prices in more supply inelastic markets relative to elastic markets, and home equity values determined by property supply constraints affect borrowers' decisions. As we study commercial mortgages, we use office supply elasticities estimated in Chapter Three and offer an insight into their impact on early mortgage termination options. To our knowledge, this study represents the first empirical attempt to cover mortgage default, restructuring and prepayment as well as defeasance simultaneously with a focus on geographic variation due to supply constraints.

As far as mortgage restructuring is concerned, Agarwal et al. (2011)[5] and Piskorski et al. (2010)[135] show that securitization reduces the likelihood of renegotiation and increases the likelihood of foreclosure. Modifications of bank held loans is more efficient as bank-held loans have lower post-modification default rates relative to securitized residential mortgages. Furthermore Favara and Giannetti (2017[68]) find that lenders are more inclined to renegotiate troubled mortgages before they become seriously delinquent, while Scharlemann and Shore (2016[152]) and Scheiser and Gross (2016[153]) obtain similar results and show that liquidity-constrained borrowers likely enrol in mortgage modification programs, which help to reduce the default probability and/or the likelihood to re-default. Downs and Xu (2015[60]), and Black et al. (2017[29]) focus on commercial mortgages and emphasize the important role of special servicers in decision making processes of modification vs foreclosure, considering that CMBS loans cannot be modified until after they have been transferred to a special servicer. Banks are more likely to extend bank loans relative to securitized loans in distress. At the same time, so far the role of property supply constraints on restructuring is ignored and we contribute to this important issue.

Furthermore, if we then analyze the second pair of competing options, defeasance is either investigated theoretically by Dierker, Quan and Torous (2005[59]) and Varli and Yildirim (2015[173]) or assumed to be equivalent to prepayment and hence treated jointly with prepayment in cash to estimate the likelihood of early mortgage termination as in An et al. (2013[16]). We improve this aspect of the literature by distinguishing between defeasance and prepayment in cash, considering that prepayment is not allowed in the lock-out period. The analysis of competing options between defeasance and prepayment in cash can help to understand the conditions needed to reduce the likelihood of early mortgage termination and hence lenders can design optimal mortgage contracts during origination.

Finally, our research is the first empirical study analyzing partial prepayment behaviour in commercial mortgage markets. In residential markets, Dagher and Kazimov (2015[52]) conclude that banks more reliant on wholesale funding curtail their credit significantly more than retail funded banks. McCollum et al. (2015[125]) find that curtailment is more likely for borrowers with higher credit scores, shorter loan terms, lower leverage at origination, current positive equity and prepayment penalty. We translate their findings into our hypotheses.

5.4 Conceptual Framework

In Chapter Four, we develop a theoretical model to price early mortgage termination options by installment option valuation approach. In this research, we further intensify the conceptual framework by building two-stage theoretical model as represented in Figure 5.1 and underpin the empirical work of our study. We build the conceptual framework underpinning the empirical work of our study on this model. Initially, we set up the estimation of the first stage by distinguishing the conditions of denying obligations and prepayments. For denying obligations, the triggering condition is reflected in the property price at the payment date j (p_j) being smaller than the remaining mortgage balance (U_{j+1}):

$$p_j < U_{j+1} \tag{5.1}$$

For prepayment options, the triggering conditions include: (1) property price at date j is greater than the remaining mortgage balance; (2) monthly market rates (r_m) are smaller than mortgage contract rates (h_m):

$$p_j > U_{j+1} \tag{5.2}$$

$$r_m < h_m \tag{5.3}$$

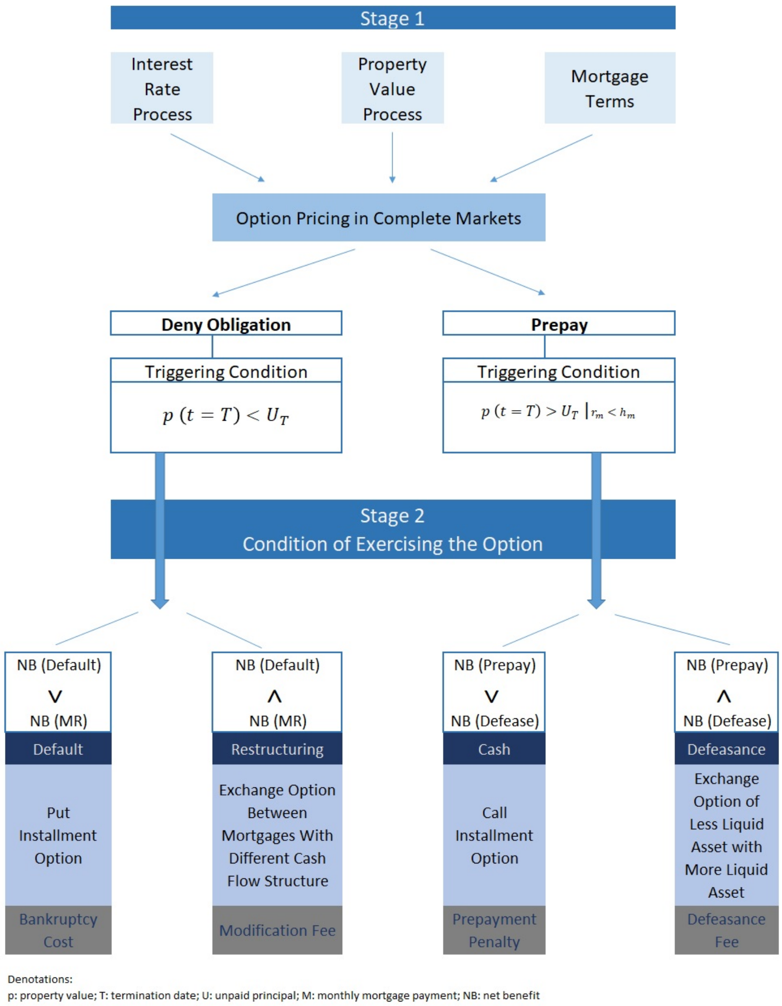


Figure 5.1: Two-stage Theoretical Option Pricing Model

In the second stage of the theoretical model, we price the values of two pairs of competing options (i.e. default vs restructuring and prepayment in cash vs defeasance) under the first stage conditions of denying obligations and prepayment by estimating net benefits (i.e. option values - execution costs). Theoretically, we analogically define early mortgage termination options with four kinds of financial options (default: installment put option, restructuring: exchange option between mortgages with different cash flow structure, prepayment: installment call option, defeasance: exchange option of less liquid assets with more liquid assets). These analogies suggest different mechanisms of pricing early termination options, so that different risk factors are expected to empirically determine the exercise of each kind of early mortgage termination. Therefore, we estimate the probabilities of two pairs of competing options by setting two groups of mort-

gages where borrowers decide to either deny the obligation or prepay in the first stage and opt for different ways to exercise such options in a second stage.[4]
Finally, as far as the partial prepayment behaviour is concerned, we combine it with early mortgage termination although the mortgage is not fully terminated and we treat it as a decision involving unscheduled balloon payments. Two types of partial prepayment behaviour exist: curtailment (or partial prepayment in cash) and partial defeasance. Therefore, when we identify the two-stage model, we add partial prepayment as one of the outcomes in the first stage, as well as an extra pair of competing options (curtailment vs partial defeasance) in the second stage. Moreover, we capture the impact of Treasury yields in the empirical model to investigate whether defeasance costs proxied by Treasury yields affect the likelihood of prepayment in cash and defeasance either partially or in full.

5.5 Empirical Strategy

5.5.1 Empirical Models

We follow the theoretical framework to build a two-stage model. In the first stage, we employ a multinomial logit model to estimate the likelihood of denying obligations and prepayment, either partially or in full. In the second stage, we employ a logit model to analyze three pairs of competing options: (1) default vs restructuring; (2) prepayment in cash vs defeasance; and (3) curtailment vs partial defeasance. For the multinomial logit model in the first stage, we classify each mortgage m by its status ms: 0 for performing mortgages, 1 for denying obligations (i.e. combination of default and restructuring), 2 for full prepayment (i.e. combination of prepayment in cash and defeasance) and 3 for partial prepayment (i.e. combination of curtailment and partial defeasance). We then assess the likelihood of option exercise π using key microeconomic variables described in Table 5.2. The empirical model for the first stage is represented as follows:

$$
\begin{aligned}
log\frac{\pi(l,ms=1,2,3)}{\pi(l,ms=0)} &= a_{0ms} + a_{1ms}LTV_{m,t} + a_{2ms}TTM_{m,t} + a_{3ms}BPR_{m,t} \\
+a_{4ms}NAR_{m,t} &+ a_{5ms}MR_{m,t} + a_{6ms}MT_m + a_{7ms}CC_m + a_{8ms}PPYM_{m,t} \\
&+a_{9ms}DSCR_{m,t} + a_{10ms}PA_{m,t} + a_{11ms}OR_{m,t} + a_{12ms}CTL_m \\
+a_{13ms}PSE_m &+ a_{14ms}\Delta PAR_{m,t} + a_{15ms}\Delta FMR_{m,t} + a_{16ms}\Delta ITY_{m,t} \quad (5.4)
\end{aligned}
$$

[4] Compared with the theoretical option pricing model, our empirical models ignore execution costs because panel data related to bankruptcy costs, modification fees and defeasance fees (except that we use Treasury yield to proxy defeasance costs for analyzing full and partial prepayment behaviour) is not available.

In the second stage, three logit models are estimated separately to study the likelihood of restructuring (1) relative to default (0), defeasance relative to prepayment in cash (respectively 1 and 0), and partial defeasance relative to curtailment (respectively 1 and 0). Table 5.2 describes the independent variables used in the three models represented as follows:

$$
\begin{aligned}
log\frac{\pi_m}{1-\pi_m} &= b_{0ms} + b_{1ms}LTV_{m,t} + b_{2ms}TTM_{m,t} + b_{3ms}BPR_{m,t} \\
+b_{4ms}NAR_{m,t} &+ b_{5ms}MR_{m,t} + b_{6ms}MT_m + b_{7ms}CC_m + b_{8ms}PPYM_{m,t} \\
&+b_{9ms}DSCR_{m,t} + b_{10ms}PA_{m,t} + b_{11ms}OR_{m,t} + b_{12ms}CTL_m \\
+b_{13ms}PSE_m &+ b_{14ms}\Delta PAR_{m,t} + b_{15ms}\Delta FMR_{m,t} + b_{16ms}\Delta ITY_{m,t} \quad (5.5)
\end{aligned}
$$

where π is probability of mortgage m being restructured (default vs restructuring), fully defeased (prepayment in cash vs defeasance), or partially defeased (curtailment vs partial defeasance) in three separate models.

We design this two stage model to estimate the probability of denying obligations and full prepayments as well as partial prepayments in the first stage and then combine the likelihood of four types of early mortgage termination options and two types of partial prepayment options in the second stage as conditional probabilities. Furthermore, we can estimate the probabilities of four types of early mortgage termination options in separate conditions (i.e. P(denying obligations and default), P(denying obligations and restructuring), P(prepayment and cash settlement) and P(prepayment and defeasance)) as well as the probabilities of two types of partial prepayment options - i.e. P(partial prepayment and curtailment) and P(partial prepayment and partial defeasance).

5.5.2 Factors Driving the Exercise of Termination Options

The hypotheses are tested using relative risk ratios in a multinomial logit model. The concept of relative risk refers to the likelihood of early mortgage termination options and partial prepayment behaviour relative to performing mortgages. If the relative risk ratio is greater (smaller) than 1, the probability of early mortgage termination or partial prepayment will be increased (decreased) by the variable of interest relative to performing loans. Table 5.1 summarizes the hypothesized relative risk ratio of independent variables, whose theoretical support is explained below.

Loan-to-value (LTV) represents the ratio between outstanding loan balance (unpaid mortgage) and the original property value as no update on the initial valuation is available. Its inverse proxy represents a situation of over-collateralization which can help to reduce mortgage default (Fabozzi 2006[67]). For denying obligations, the relative risk ratio is expected to be greater than 1, with an increase in LTV augmenting the likelihood of obligation denial. On the other hand, high debt levels stimulate deleveraging via prepayments. Therefore a positive relationship between the likelihood of prepayment and LTV is expected. Furthermore, incentives to deleverage also lead to curtailment and partial defeasance as it makes refinancing with higher loan amounts easier. Thus, the relative risk ratio of LTV is expected to be greater than 1 for partial prepayment too.

Time to maturity: based on credit risk studies such as Fabozzi (2006), credit default is highest at maturity. When the mortgage is far away from the maturity date, a lower default risk is expected, but no clear expectation for prepayment can be formed. Considering the partial prepayment behaviour, future savings in reduced interest payments may offer financial benefits for borrowers with longer terms, so a relative risk ratio greater than 1 is expected for partial prepayment - see McCollum et al. (2015 [125]).

Balloon payment ratios: Goldberg and Capone (2002[91]) explain that a part of principal is required to repay earlier, and thus the risk of denying the obligation should be higher. A positive relationship between the balloon payment and the likelihood of denying obligations is expected, but there is no conclusion on either full or partial prepayment.

Negative amortization rate: negative amortization refers to deferred payment. Brueggeman et al.(2011) point out that higher payments should be made near the maturity of mortgages, but lower payments are made before maturity. Therefore, a lower probability of denying obligations before maturity is expected, but the probability should increase at maturity. Finally, no theoretical support clearly suggest a unique relationship between negative amortization and either full or partial prepayment risk.

Mortgage rate: Ciochetti et al. (2002[44]) and Chen and Deng (2013[37]) conclude that a higher borrowing rate leads to a greater mortgage payment and higher borrowing costs cause higher likelihood of default and prepayment. Therefore, both relative risk ratios are expected to be greater than 1. Similarly, higher borrowing costs stimulate partial prepayment.

Interest only type, i.e. IOM: Corcoran (2000) and Brueggeman et al. (2011) point out that no principal is repaid until maturity for interest-only mortgages and therefore a lower and higher likelihood of denying obligations is expected respectively before and at maturity. The relationships between IOMs and prepayment risk cannot be inferred a priori.

Cross-collateralization: it represents a type of credit enhancement term to reduce default risk. The mechanism is that all properties serving as collateral for individual loans will serve to collateralize the entire debt as represented by a cross-collateralization agreement. The lender is allowed to call each mortgage within the pool when any one defaults (Fabozzi 2006[67], Brueggeman et al. 2011[33]). Endogeneity in the underwriting process (i.e. a lender assigning cross collateralization in mortgage contracts for less credible borrowers) may make the role of cross-collateralization ambiguous. Therefore, we do not form any expectations about the relationship between cross-collateralization and default and prepayment risks.

Prepayment penalty / yield maintenance: negative relationships are expected between prepayment penalty / yield maintenance and prepayment risk. Elliehausen et al. (2008[62]) show that the default risk premium is inversely related to the presence of a prepayment penalty for fixed-rate and variable-rate mortgages and directly related to prepayment penalty for hybrid mortgages. This shows an unclear relationship between prepayment penalty and denying obligations. As far as the partial prepayment behaviour is concerned, if prepayment penalty / yield maintenance is too high for prepayment in full, borrowers will choose to partially prepay to reduce future interest payments. Thus, the relative risk ratio is expected to be greater than 1 for partial prepayment.

Debt service coverage ratio (DSCR): the ratio between periodical income and mortgage payment represents the borrower's financial ability to repay period after period. Therefore, the DSCR negatively correlates with the probability of default and the relative risk ratio should be smaller than 1 for denying obligations. This hypothesis is supported by findings in An et al. (2013[16]), Goldberg and Capone (2002[91]) and Seslen and Wheaton (2010[154]). Moreover, higher debts stimulate borrowers to prepay to achieve a reduction in debt level when they are financially capable to do so. Therefore, no unique relationship is expected between DSCR and (full and partial) prepayment risk.

Property age: older properties require more maintenance and hence operating costs may increase. They are also risky as the cost is more uncertain - see Archer et al. (2002 [20]). This reduces the incentive to early terminate mortgages. On the other hand, mortgages for developments are also risky. As a result, a non-linear relationship between property age and probability of denying obligations and prepayments are expected. Therefore, we cannot exactly infer unique expectations on relative risk ratios for prepayment.

Occupancy rate: income-producing properties rely on a stable income flow to maintain solvency. The occupancy rate can be used to determine income stability as explained by An et al. (2013 [16]) and Chen and Deng (2013 [37]). A higher occupancy rate is expected to reduce the likelihood of denying obligations. Stable income can provide credits to mortgage borrowers and encourage prepayments. So, the higher the occupancy rate, the greater the prepayment risk. If borrowers earn greater income driven by higher occupancy, they will be more capable of prepaying partially or in full. So relative risk ratios are expected to be greater than 1.

Credit Tenant Lease: Brueggeman et al. (2011) mentions that credit tenant lease reduces the risk of mortgage default as credit tenants are unlikely to default and therefore the relative risk ratio is expected to be smaller than 1. No conclusion can be reached for the expected impact of credit tenant lease on prepayment risk instead.

Property supply elasticity: Hilber and Vermeulen (2016[105]) find that property supply constraints negatively affect fluctuations in property prices, with more inelastic markets showing higher volatility. Hence, mortgage default is more likely to occur in supply inelastic areas. As a result, relative risk ratios should be smaller than 1 for denying obligations. Moreover, as supply inelastic property markets are more volatile, a greater uncertainty of property prices is expected and borrowers cannot easily predict future movements. Therefore, on one hand they may decide to cash in realised gains from capital appreciation by refinancing with higher outstanding loan balance (assuming available LTVs are confirmed as for the previous origination) and distributing the excess value. On the other hand, however, borrowers may prefer to retain the opportunity of further price appreciation by only partially prepaying. In other words, we argue that borrowers strategically prepay a partial amount of the outstanding loan balance to cash in a guaranteed minimum capital gain, but they want to keep the option of further uplift for the remaining part which is not prepaid. As a result, a positive and negative relationship between property supply elasticity and respectively full and partial prepayments is expected.

Property absorption rate: intuitively, less property take-up causes a gloomier outlook on commercial property and a higher mortgage default risk is expected. A negative relationship is expected between office using employment and the probability of denying obligations. This is supported by the findings in An et al.

(2013 [16]). Greater demand may reflect higher income and higher occupancy, thus a greater prepayment risk is expected (i.e. a positive relationship between property absorption rate and prepayment risk). As far as partial prepayment behaviour is concerned, the greater the likelihood of prepayment in full, the less the likelihood of partial prepayment. In other words, a negative relationship between property absorption rate and the likelihood of partial prepayment is expected.

Fixed rate mortgage - FRM - market rate: it demonstrates the market trend of interest rates, which is also discussed in Ambrose and Sanders (2003[15]). In a low interest rate environment, the prepayment risk rises. That leads to the expectation of a negative relationship between market interest rates and prepayment risk. However, in general interest rates positively correlate with property prices. If borrowers want to cash in realised profits through property price appreciation using prepayment, they will more likely do this in an environment with interest rates increasing. Hence, a negative relationship between market interest rates and prepayment becomes unsure. Furthermore, if market interest rates increase, the default risk may increase for adjustable rate mortgage (ARM) borrowers but less so for FRM borrowers. Therefore, we assume the relationship between the likelihood of denying obligations and market interest rates should be empirically determined.

Inflation indexed Treasury yield: we only examine the impact of Treasury yields on full and partial prepayment bahaviour. Dierker et al. (2005[59]) mention that Treasury yields proxy for the cost of defeasance as it requires the submission of Treasury securities which replicate cash flow patterns of mortgages. If Treasury yields are high, a greater defeasance cost is determined and hence a lower likelihood of full or partial defeasance is expected. Odd ratios in the second stage model for full or partial defeasance are expected to be smaller than 1 relative to full prepayment in cash or curtailment.

Table 5.1: Hypothesis Tests

Acronym	Variable	Relative Risk Ratio		
		Denying obligations	**Full Prepayments**	**Partial Prepayments**
$LTV_{m,t}$	LTV ratio (%)	>1	>1	>1
$TTM_{m,t}$	Time to Maturity (month)	<1	?	>1
$BPR_{m,t}$	Balloon Payment Ratio (%)	>1	?	?
$NAR_{m,t}$	Negative Amortization Rate (%)	?	?	?
$MR_{m,t}$	Mortgage Rate (%)	>1	>1	>1
MT_m	Mortgage Type (Interest Only)	?	?	?
CC_m	Cross Collateralization	?	?	?
$PPYM_{m,t}$	Prepayment Penalty & Yield Maintenance (%)	?	<1	>1
$DSCR_{m,t}$	Debt Service Coverage Ratio (%)	<1	?	?
$PA_{m,t}$	Property Age (Year)	?	?	?
$OR_{m,t}$	Occupancy Rate (%)	<1	>1	>1
CTL_m	Credit Tenant Lease	<1	?	?
PSE_m	Property Supply Elasticity	<1	>1	<1
$PAR_{m,t}$	Property Absorption Rate in MSA	<1	>1	<1
FMR_t	Fixed Rate Mortgage Market Rate (%)	?	?	?
ITY_t	Inflation Indexed Treasury Yield (%)	?	?	?

5.5.3 Data and Data Sources

Securitized commercial mortgage databases are compiled by four main institutions - namely Trepp, Intex, Morningstar and Bloomberg. In this research, we obtain data support from Trepp, which maintains the most comprehensive database in the coverage of 15,266 commercial mortgages starting from 1998. More than 500 loan specifications are recorded for each loan. In total, there are more than two million observations. As we focus on mortgages collateralized by office buildings in 42 metropolitan statistical areas (MSA thereafter)[5], we therefore trim the dataset by selecting relevant mortgages and filtering the records with missing data such as origination date, maturity date, LTV ratio, debt service coverage ratios (DSCR), mortgage rates, property occupancy rates and collateral's location etc. We also delete mortgage records with multiple statuses, for example "simultaneous" default and prepaid loans, and records with changing loan statuses after being in default, prepaid in cash and defeased. Furthermore, we identify and remove outliers based on following conditions: (1) LTV ratio greater than 1000%, (2) balloon payment ratio greater than 500%, (3) mortgage rate greater than 500%, (4) DSCR with negative sign[6] . As a result, 12,453 commercial mortgages totalling 989,851 observations are available for our empirical analysis on early termination options. The unbalanced panel dataset is compiled for the time period between March 2001 and August 2017.

Table 5.2 summarizes the descriptive statistics for 17 variables, with property supply elasticities obtained in Chapter Three. The data series of property demand factor (e.g. property absorption rate by MSA) are obtained from CBRE Econometric Advisor. Other mortgage related data are sourced from Trepp. In general, the extremely large skewness and kurtosis reflect fat tailed distributions on several variables including LTV ratio, balloon payment ratios, negative amortization rate, mortgage rate, prepayment penalty and yield maintenance and debt service coverage ratios.

For our main analysis, table 5.3 reports the descriptive stats of our variables for the seven types of mortgage status: defaulted, restructured, prepaid, defeased, curtailed, partially defeased and performing. To define mortgage default, we check the delinquency status. If the delinquency lasts longer than 90 days or a mortgage is classified as "real estate owned" or "foreclosed", the mortgage is

[5]As our estimations of property supply elasticity covers 42 MSAs, we compile the dataset of mortgages granted in these MSAs.

[6]Garmaise (2015[80]) and Griffin and Maturana (2016[94]) point out the misreporting behaviour in mortgage markets which is associated with higher likelihood of mortgage delinquency. Thus, we pay attention on outliers to avoid distorting the estimation results.

classified as “defaulted". Of four types of early mortgage termination options, most mortgages are prepaid (7,031), while restructuring is the least to occur (501). As far as mortgage terms are concerned, defaulted mortgages have the highest LTV ratios and holding time. That means that highly levered loans are more likely to default, but borrowers take the longest time to make decisions. In terms of amortization, it is surprising that prepaid mortgages do not have balloon payments and negative amortization driven by deferred interests. Defeased mortgages have absolutely enormous balloon payments but no negative amortization. Prepayment in cash and defeasance are sensitive to market interest rates as borrowers consider the costs of interest in the property boom period. Prepaid and defeased mortgages have the highest mortgage rates comparing with performing mortgages. By intuition, borrowers would save interest payments by early terminating mortgages. In contrast, restructuring by reducing mortgage rates obtain the lowest mortgage rates. Interestingly prepayment penalty and yield maintenance tend to zero for prepaid and defeased mortgages and this enhances incentives to prepay. On the other hand, borrowers more likely deny obligations for interest only mortgages, particularly through restructuring. Considering collateral terms, default mortgages have the lowest DSCR, property age and occupancy rates. Concerning property supply constraints, restructured, prepaid and defeased mortgages have lower supply elasticities than performing mortgages, and only defaulted mortgages have the highest supply elasticities. This may be explained by a much longer decision time in supply inelastic markets where greater fluctuations in property prices are unrealized. In other words, borrowers with collateral in more elastic markets make quicker decisions to default although fluctuations in property prices are smaller. In terms of property demand factors, higher property absorption rates are found in restructured and prepaid mortgages. This may suggest a stronger demand force encouraging restructuring when borrowers decide to deny obligations and prepayment in cash when borrowers want to prepay. To confirm these findings, we will estimate the models previously presented and discuss main results in the next section.

Finally, to investigate partial prepayment behaviour, we identify curtailment and partial defeasance based on the related signals given in the Trepp database, where we observe only 301 curtailed mortgages and 6 partially defeased ones. We jointly analyze partial prepayment and early mortgage termination, because borrowers may consider both of them during low interest rate periods to reduce service charges. Therefore, we add an extra outcome (i.e. partial prepayment) in the first stage model and an extra pair of competing options (i.e. curtailment vs partial defeasance) in the second stage model. Comparing descriptive statistics, longer time to maturity, higher balloon payment ratios, lower mortgage rates, more IOMs and greater property supply elasticities are found in curtailed than in fully prepaid mortgages. Higher LTV ratios, balloon payment ratios, and lower mortgage rates and Treasury yields are found in partially than fully defeased mortgages.

Table 5.2: Data Summary Statistics For All Mortgages

Acronym	**Variable**	**Mean**	**S.D.**	**Min.**	**Max.**	**Skewness**	**Kurtosis**
$LTV_{m,t}$	LTV ratio (%)	71.926	31.263	1.34	994.62	7.141	95.004
$HT_{m,t}$	Holding Time (month)	63.911	36.357	0	360	0.478	3.389
$TTM_{m,t}$	Time to Maturity (month)	72.536	63.151	1	477	2.21	8.898
$BPR_{m,t}$	$^{(a)}$ Balloon Payment Ratio (%)	79.539	33.526	-1.23×10^{-5}	500	-1.696	5.336
$NAR_{m,t}$	$^{(b)}$ Negative Amortization Rate (%)	-0.001	0.1002	-16.601	22.897	-93.857	17678.71
$MR_{m,t}$	Mortgage Rate (%)	6.271	1.486	0.0001	398.292	111.429	29294
MT_m	$^{(c)}$ Mortgage Type (Interest Only)	0.453	0.721	0	2	1.254	3.049
CC_m	Cross Collateralization	0.033	0.178	0	1	5.262	28.684
$PPYM_{m,t}$	$^{(d)}$ Prepayment Penalty & Yield Maintenance (%)	0.006	0.292	0	56.724	67.546	6297.755
$DSCR_{m,t}$	Debt Service Coverage Ratio (%)	1.549	0.816	0.001	154.61	21.016	2684.099
$PA_{m,t}$	Property Age (Year)	33.524	27.436	0	278	1.752	6.799
$OR_{m,t}$	Occupancy Rate (%)	91.314	12.317	1.059	100	-2.263	9.989
CTL_m	Credit Tenant Lease	0.005	0.073	0	1	13.626	186.656
PSE_m	Property Supply Elasticity	0.111	0.107	0	0.377	1.079	3.41
$PAR_{m,t}$	Property Absorption Rate in MSA (%)	0.322	0.74	-4.152	5.724	0.305	5.865
FMR_t	Fixed Rate Mortgage Market Rate (%)	4.536	1.171	2.658	6.508	-0.086	1.555
ITY_t	Inflation Indexed Treasury Yield (%)	1.251	0.921	-0.77	2.89	-0.43	2.176

Notes: 12453 mortgages consist of 989851 observations. The unbalanced panel data starts from March 2001 and ends at August 2017. (a) Balloon payment ratio is computed as scheduled balloon payment divided by mortgage balance. (b) Negative amortization is computed as deferred interest or negative amortization divided by mortgage balance. (c) Mortgage type is category variables (i.e. fully interest only=2, partial interest only=1, none=0). (d) This is the ratio of prepayment penalty and yield maintenance to mortgage balance.

Table 5.3: Data Summary Statistics By Mortgage Status

	Default		Restructured		Prepaid		Defeased		Curtailed		Partial Defeased		Performing	
Variable	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
$LTV_{m,t}$	163.506	90.853	124.803	62.323	78.538	48.976	66.957	10.892	71.98	36.965	75.408	6.339	67.506	15.451
$HT_{m,t}$	88.264	30.798	91.611	25.413	86.88	59.317	92.59	27.26	98.993	32.289	75.042	22.081	59.41	34.34
$TTM_{m,t}$	43.298	54.251	37.901	42.761	69.484	65.21	52.225	70.53	145.908	107.436	68.982	77.738	75.799	62.081
$BPR_{m,t}$	92.408	23.302	92.486	36.8	0	0	78.222	36.875	90.979	42.179	84.294	30.503	81.549	30.616
$NAR_{m,t}$	-0.001	0.031	-0.065	0.878	0	0	0	0	-0.023	0.074	0	0	-0.0001	0.0123
$MR_{m,t}$	6.23	0.895	5.719	1.352	6.734	1.373	6.769	1.16	6.063	1.306	6.151	0.971	6.227	1.523
MT_m	0.838	0.763	1.424	0.78	0.368	0.687	0.225	0.524	0.788	0.824	0.97	0.446	0.442	0.716
CC_m	0.039	0.194	0.064	0.244	0.038	0.191	0.037	0.189	0.013	0.114	0	0	0.031	0.174
$PPYM_{m,t}$	0.002	0.131	0.003	0.177	0	0	0	0	0.012	0.301	0	0	0.007	0.314
$DSCR_{m,t}$	1.052	0.467	1.358	1.22	1.515	0.952	1.491	0.489	1.767	1.064	1.229	0.59	1.577	0.827
$PA_{m,t}$	31.398	22.927	34.799	23.636	35.472	27.38	40.379	30.378	29.395	17.927	41.916	35.853	33	27.356
$OR_{m,t}$	75.776	20.674	82.656	16.176	89.857	15.646	94.337	7.978	92.982	12.478	82.212	8.824	91.899	11.408
CTL_m	0.002	0.049	0.0001	0.009	3.54×10^{-5}	0.006	0.002	0.041	0	0	0	0	0.006	0.077
PSE_m	0.131	0.107	0.095	0.098	0.108	0.107	0.106	0.109	0.135	0.107	0.067	0.051	0.111	0.107
$PAR_{m,t}$	0.283	0.631	0.341	0.6	0.465	0.691	0.194	0.704	0.268	0.629	0.471	0.645	0.328	0.75
FMR_t	3.57	0.762	3.489	0.866	4.62	1.329	4.689	1.166	3.617	0.904	3.613	0.8	4.579	1.158
ITY_t	0.518	0.76	0.433	0.761	1.264	0.994	1.348	0.9	0.536	0.823	0.557	0.777	1.288	0.909
Number of Loans	1953		501		7031		1855		301		6		12129	
Observations	35089		12597		28268		65985		1753		166		845993	

Notes: $LTV_{m,t}$: LTV ratio, $HT_{m,t}$: Holding Time, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $OE_{m,t}$: Office Using Employment in MSA, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.

5.5.4 Data Issues

Possibility of Outliers

Although we have dropped outliers as aforementioned, the data summary (Table 5.2) still indicates the possibility of an impact from outliers on five variables: LTV ratios, balloon payment ratios, mortgage rate, DSCR and property age. In order to eliminate this possibility, we winsorize these five variables at 5% level for each tail. Table 5.4 summarizes the statistics of winsorized variables. The statistics show that outliers are eliminated by winsorization.

Multicollinearity

We compile a correlation matrix for 16 variables in Table 5.5. As all correlation coefficients among 16 variables are low. This indicates that the risk of multi-collinearity is low in our model set up.

Unobserved Heterogeneity

In order to deal with unobserved heterogeneity, the study by Seslen and Wheaton (2010[154]) includes fixed loan age effects in the models. However, we argue that this approach cannot fully capture time-varying unobserved factors as same loan ages exist in different time periods. Therefore, we apply conventional fixed time effects in regression models to consider time varying unobserved heterogeneity. Furthermore, locational unobserved heterogeneity may exist as there may be different requirements related recourse loans by states and we then apply fixed state effects. Along with significant fixed time effects, we also find statistically significant results for state dummies which implies significant effects of locational unobserved heterogeneity on early mortgage termination (Table 5.6).

Table 5.4: Data Summary for Winsorized Variables

Acronym	**Variable**	**Mean**	**S.D.**	**Min.**	**Max.**
$LTV_{m,t}$	LTV ratio (%)	68.167	10.798	42.3	83.5
$BPR_{m,t}$	Balloon Payment Ratio (%)	79.239	32.993	0	100
$MR_{m,t}$	Mortgage Rate (%)	6.282	1.022	4.806	8.370
$DSCR_{m,t}$	Debt Service Coverage Ratio (%)	1.504	0.460	0.750	2.617
$PA_{m,t}$	Property Age (Year)	32.834	24.950	5.000	96.000

Table 5.5: Correlation Matrix

	LTV	TTM	BPR	NAR	MR	MT	CC	PPYM	DSCR	PA	OR	CTL	PSE	PAR	FMR	ITY
TTM	-0.06	1														
BPR	0.11	-0.39	1													
NAR	-0.02	-0.02	-0.03	1												
MR	-0.06	-0.09	-0.09	-0.007	1											
MT	0.07	-0.12	0.49	-0.008	-0.37	1										
CC	0.05	-0.01	-0.004	-0.01	0.01	-0.01	1									
PPYM	-0.01	-0.02	-0.002	-0.003	0.02	-0.01	0.002	1								
DSCR	-0.39	0.09	-0.06	0.01	-0.13	-0.003	-0.02	0.007	1							
PA	-0.13	-0.10	0.08	-0.002	-0.05	0.10	-0.03	0.003	0.02	1						
OR	-0.08	0.14	-0.1	-0.005	0.07	-0.11	-0.002	0.001	0.29	-0.15	1					
CTL	-0.03	0.05	-0.02	0.002	-0.05	0.02	0.001	-0.002	0.02	0.02	0.003	1				
PSE	0.21	-0.01	-0.01	-0.001	-0.01	-0.04	0.05	-0.01	-0.09	-0.16	-0.10	0.004	1			
PAR	-0.02	0.01	-0.02	0.00	0.01	-0.03	-0.01	0.002	0.01	0.01	0.01	-0.001	-0.06	1		
FMR	-0.06	0.31	-0.26	0.02	0.32	-0.39	0.02	0.01	0.08	-0.13	0.12	-0.05	-0.01	0.06	1	
ITY	-0.07	0.31	-0.27	0.02	0.34	-0.37	0.02	0.01	0.09	-0.13	0.12	-0.04	-0.01	0.06	0.21	1

Table 5.6: Fixed State Effects

State	D or R	P or Df	C or PD
California	-0.525***	-0.391***	-1.040***
Colorado	-0.121**	-0.334***	-0.202
Connecticut	-0.682***	-0.306***	-0.822***
District of Columbia	-1.350***	0.308***	-1.337***
Delaware	-0.502***	-0.626***	-0.389
Florida	-0.231***	-0.306***	-1.039***
Georgia	-0.069*	-0.388***	-0.980***
Illinois	-0.433***	-0.636***	0.500***
Indiana	-0.138**	-0.730***	0.492**
Kansas	-0.641***	-0.716***	-3.243***
Kentucky	-0.336**	-0.744***	-27.565
Massachusetts	-0.653***	-0.104***	-1.210***
Maryland	-0.825***	-0.292***	-0.537***
Michigan	-0.276***	-1.267***	-0.925***
Missouri	0.091*	-0.620***	-1.253***
North Carolina	-0.701***	-0.505***	-2.846***
New Hampshire	-1.781***	-0.674***	-26.302
New Jersey	-0.220***	-0.341***	-0.484***
New York	-0.212***	0.186***	-1.818***
Ohio	-0.347***	-1.026***	0.269*
Pennsylvania	-0.314***	-0.387***	-0.965***
South Carolina	-0.871***	1.520***	-27.208
Texas	-0.532***	-0.816***	-1.611***
Virginia	-0.966***	-0.116***	-0.465***
Vermont	-17.956	-27.781	-29.318
Washington	-0.492***	-0.353***	-3.646***
West Virginia	-22.964	2.082***	-27.668

Notes:
D, R, P, Df, C and PD mean Default, Restructured, Prepaid, Defeased, Curtailed and Partially Defeased.
The results are generated by Model M4 and the reported values are the coefficients of state dummy variables.
***, ** and * represent significant level at 1%, 5%, 10%.

5.6 Estimation Results and Discussion

In line with theoretical models, we employ a two-stage regression model in our empirical analysis. In the first stage, we adopt a multinomial logit model (performing = 0; denying obligations = 1; prepayment options = 2; partial prepayment = 3). In the second stage, we use a logit model to investigate borrowers' decisions when they deny obligations (default vs restructuring), fully prepay (prepayment in cash vs defeasance), or partially prepay (curtailment vs partial defeasance).

5.6.1 Early Mortgage Termination

In the first stage, default or restructuring is equivalent to denying obligations, prepayment in cash or defeasance represent prepayment options, and partial prepayment includes curtailment or partial defeasance. We set up four models where we: (1) exclude property demand factors, mortgage market rates and Treasury yield; (2) include property demand factors only; (3) include mortgage market rates and Treasury yield; (4) include all property demand factors, mortgage market rates and Treasury yield.

Tables 5.7 and 5.8 report the main results. Findings are consistent with theoretical expectations except for the effect of credit tenant lease on the likelihood of denying obligations and the impact of occupancy rate on the likelihood of partial prepayment. Based on the Bayesian Information Criteria, Model 4 is the best fit. Among mortgage terms, negative amortization rate, mortgage rates and mortgage type (interest only), exhibit statistically and economically significant impact on the likelihood of obligation denial: a 1% increase in each of these variables determines respectively a 91% decrease and 110% and 63% increase in the probability. Despite cross-collateralization being a protection covenant for lenders, we find that this phenomenon does not reduce the likelihood of obligation denial while, instead, a 1% increase in cross-collateralization makes the probability increase by 18%. This result reflects the endogeneity of the underwriting process. Furthermore, prepayment penalty / yield maintenance works as a tool to prevent prepayment as it causes a 2% reduction in the likelihood of obligation denial.

Importantly, the LTV ratio shows a significant impact on the decision to deny obligations, with a 1% change causing a 34% shift in the probability of default. Hence, the careful consideration banking regulators assign to this metric is justified, especially considering the impact on banking losses in case of option exercise. Furthermore, other collateral related terms also exert a significant impact on the decision of denying obligations: a 1% increase in DSCR reduces the likelihood of denying obligation by 21%.

Finally, we find evidence of our main hypothesis that property supply constraints is important and consequently banking regulators should carefully consider the geographical composition of the lending portfolio. If the supply elasticity of a market increases by one unit, the likelihood of denying obligation drops by 55%. Therefore, relaxing supply constraints can reduce the possibility of denying obligation and can be seen as an alternative risk management tool to control systemic default risk and spillover effects.

Table 5.7: Two-Stage Model (Winsorized): The First Stage -Multinomial Logit Model Results - Coefficients

Independent Variables	M1			M2			M3			M4		
	D or R	**P or Df**	**C or PD**	**D or R**	**P or Df**	**C or PD**	**D or R**	**P or Df**	**C or PD**	**D or R**	**P or Df**	**C or PD**
$LTV_{m,t}$	0.127***	0.007***	0.010***	0.127***	0.007***	0.010***	0.289***	0.010***	0.021***	0.289***	0.010***	0.021***
	(0.001)	(0.0004)	(0.003)	(0.001)	(0.0004)	(0.003)	(0.002)	(0.0004)	(0.003)	(0.002)	(0.0004)	(0.003)
$TTM_{m,t}$	-0.005***	-0.005***	0.010***	-0.005***	-0.005***	0.010***	-0.004***	-0.005***	0.010***	-0.004***	-0.005***	0.010***
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0002)
$BPR_{m,t}$	0.005***	-0.018***	-0.002**	0.005***	-0.018***	-0.002**	0.007***	-0.018***	-0.001	0.007***	-0.018***	-0.001
	(0.0002)	(0.0001)	(0.001)	(0.0002)	(0.0001)	(0.001)	(0.0003)	(0.0001)	(0.0008)	(0.0003)	(0.0001)	(0.001)
$NAR_{m,t}$	-2.069***	0.091	-2.260***	-2.061***	0.092	-2.252***	-2.251***	0.080	-2.491***	-2.252***	0.080	-2.492***
	(0.253)	(0.079)	(0.259)	(0.253)	(0.079)	(0.259)	(0.287)	(0.081)	(0.291)	(0.287)	(0.081)	(0.291)
$MR_{m,t}$	0.478***	0.474***	0.410***	0.477***	0.474***	0.410***	0.741***	0.529***	0.591***	0.741***	0.530***	0.591***
	(0.009)	(0.004)	(0.033)	(0.009)	(0.004)	(0.033)	(0.010)	(0.004)	(0.033)	(0.010)	(0.004)	(0.033)
MT_m	0.609***	-0.237***	0.380***	0.609***	-0.237***	0.380***	0.490***	-0.223***	0.402***	0.490***	-0.223***	0.402***
	(0.008)	(0.007)	(0.033)	(0.008)	(0.007)	(0.033)	(0.009)	(0.007)	(0.034)	(0.009)	(0.007)	(0.034)
CC_m	0.191***	0.163***	-0.879***	0.191***	0.163***	-0.879***	0.166***	0.169***	-0.871***	0.166***	0.170***	-0.871***
	(0.028)	(0.020)	(0.219)	(0.028)	(0.020)	(0.219)	(0.031)	(0.020)	(0.222)	(0.031)	(0.020)	(0.222)
$PPYM_{m,t}$	-0.030	-215.5425	0.040	-0.030	-203.265	0.040	-0.022	-340.769	0.043	-0.022	-340.807	0.043
	(0.034)	(3920.91)	(0.045)	(0.034)	(3319.07)	(0.045)	(0.036)	(22545)	(0.046)	(0.036)	(22544)	(0.046)
$DSCR_{m,t}$	-0.589***	-0.282***	0.528***	-0.585***	-0.282***	0.527***	-0.240***	-0.232***	0.800***	-0.240***	-0.231***	0.800***
	(0.017)	(0.010)	(0.062)	(0.017)	(0.010)	(0.062)	(0.019)	(0.010)	(0.062)	(0.019)	(0.010)	(0.062)
$PA_{m,t}$	-0.002***	0.007***	-0.003***	-0.002***	0.007***	-0.003***	-0.0001	0.007***	-0.004***	-0.0001	0.007***	-0.004***
	(0.0003)	(0.0002)	(0.001)	(0.0003)	(0.0002)	(0.001)	(0.0003)	(0.0002)	(0.001)	(0.0003)	(0.0002)	(0.001)
$OR_{m,t}$	-0.033***	0.018***	0.007***	-0.033***	0.018***	0.007***	-0.037***	0.013***	-0.004**	-0.037***	0.013***	-0.004**
	(0.0003)	(0.0004)	(0.002)	(0.0003)	(0.0004)	(0.002)	(0.0004)	(0.0004)	(0.002)	(0.0004)	(0.0004)	(0.002)
CTL_m	-0.326***	-1.409***	-19.742	-0.326***	-1.409***	-19.375	0.031	-1.393***	-26.267	0.031	-1.393***	-26.268
	(0.118)	(0.098)	(4204.59)	(0.118)	(0.098)	(3496.88)	(0.134)	(0.099)	(113345)	(0.134)	(0.099)	(113357)
PSE_m	-0.999***	1.487***	-0.908***	-0.982***	1.491***	-0.907**	-0.814***	1.519***	-0.647	-0.800***	1.523***	-0.647
	(0.088)	(0.065)	(0.461)	(0.089)	(0.066)	(0.461)	(0.098)	(0.066)	(0.473)	(0.098)	(0.066)	(0.473)
$\Delta PAR_{m,t-3}$				-0.001***	-0.0007**	0.0004				-0.0007**	-0.0006**	-0.00002
				(0.0003)	(0.0003)	(0.003)				(0.0983)	(0.0003)	(0.003)
ΔFMR_{t-3}							3.989***	3.942***	3.989***	3.990***	3.943***	3.990***
							(0.302)	(0.191)	(0.827)	(0.302)	(0.191)	(0.827)
ΔITY_{t-3}							-0.078***	-0.076***	-0.071***	-0.078***	-0.076***	-0.071***
							(0.008)	(0.005)	(0.021)	(0.008)	(0.005)	(0.021)
Constant	-8.669	4.454	-12.046	-8.667	4.451	-12.049	-13.670***	5.828***	-0.161	-13.660***	5.827***	-0.162
	(368.935)	(58.346)	(2092.91)	(368.192)	(58.336)	(2090.51)	(0.898)	(0.577)	(2.456)	(0.898)	(0.577)	(2.456)
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y		Y	Y		Y	Y		Y	Y		Y
BIC		754364			754379			725464			725341	
Log Likelihood		-372619			-372606			-358350			-358268	
LR Chi Square		276988			276717			287774			287649	
Observations		989851			989471			964144			963766	

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $OE_{m,t}$: Office Using Employment in MSA, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
D, R, P, Df, C and PD mean Default, Restructured, Prepaid, Defeased, Curtailed and Partially Defeased.
Figures in parentheses are standard errors.
***, ** and * represent significant level at 1%, 5%, 10%.

Table 5.8: Two-Stage Model (Winsorized): The First Stage - Multinomial Logit Model Results - Relative Risk Ratio

Independent Variables	**M1**			**M2**			**M3**			**M4**		
	D or R	**P or Df**	**C or PD**	**D or R**	**P or Df**	**C or PD**	**D or R**	**P or Df**	**C or PD**	**D or R**	**P or Df**	**C or PD**
$LTV_{m,t}$	1.136***	1.007***	1.010***	1.136***	1.007***	1.010***	1.335***	1.010***	1.022***	1.336***	1.010***	1.022***
$TTM_{m,t}$	0.995***	0.995***	1.010***	0.995***	0.995***	1.010***	0.996***	0.995***	1.010***	0.996***	0.995***	1.010***
$BPR_{m,t}$	1.005***	0.982***	0.998**	1.005***	0.982***	0.998**	1.007***	0.982***	0.999	1.007***	0.982***	0.999
$NAR_{m,t}$	0.126***	1.096	0.104***	0.127***	1.096	0.105***	0.105***	1.083	0.083***	0.105***	1.083	0.083***
$MR_{m,t}$	1.612***	1.606***	1.507***	1.612***	1.606***	1.507***	2.098***	1.698***	1.805***	2.099***	1.698***	1.806***
MT_m	1.838***	0.789***	1.463***	1.838***	0.789***	1.462***	1.632***	0.800***	1.495***	1.632***	0.800***	1.495***
CC_m	1.210***	1.176***	0.415***	1.211***	1.177***	0.415***	1.181***	1.185***	0.419***	1.181***	1.185***	0.419***
$PPYM_{m,t}$	0.970	0	1.041	0.970	0	1.041	0.978	0	1.044	0.978	0	1.044
$DSCR_{m,t}$	0.555***	0.754***	1.695***	0.557***	0.755***	1.694***	0.786***	0.793***	2.225***	0.786***	0.793***	2.226***
$PA_{m,t}$	0.998***	1.007***	0.997***	0.998***	1.007***	0.997***	1.000	1.007***	0.996***	1.000	1.007***	0.996***
$OR_{m,t}$	0.967***	1.018***	1.007***	0.967***	1.018***	1.007***	0.964***	1.013***	0.996**	0.964***	1.013***	0.996**
CTL_m	0.722***	0.244***	0	0.722***	0.244***	0	1.031	0.248***	0	1.032	0.248***	0
PSE_m	0.368***	4.422***	0.403***	0.375***	4.441***	0.404**	0.443***	4.568***	0.524	0.449***	4.585***	0.524
$\Delta PAR_{m,t-3}$				0.999***	0.999**	1.0004				0.999**	0.999**	1.000
ΔFMR_{t-3}							54.001***	51.542***	54.023***	54.079***	51.566***	54.038***
ΔITY_{t-3}							0.925***	0.927***	0.932***	0.925***	0.927***	0.932***
Constant	0.0002	85.963	5.87×10^{-6}	0.0002	85.720	5.86×10^{-6}	1.16×10^{-6}***	339.648***	0.851	1.17×10^{-6}***	339.242***	0.850
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $OE_{m,t}$: Office Using Employment in MSA, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
D, R, P, Df, C and PD mean Default, Restructured, Prepaid, Defeased, Curtailed and Partially Defeased.
***, ** and * represent significant level at 1%, 5%, 10%.

At the same time, significant impacts of mortgage terms are obtained in prepayment options. The likelihood of prepayments respectively increases by 71% when rates increase by 1% and decreases by 20% for interest-only mortgages. Furthermore, as zero prepayment penalty and yield maintenance are found in prepaid and defeased mortgages (refer to table 5.3), we obtain some "zero" relative risk ratios. This finding is consistent with market practice, where prepayment in cash normally happens during the last few months of the contract when the bank does not ask for penalties and normally renegotiates the contract if the property is not sold. Similar to obligation denial, collateral related terms such as DSCR and credit tenant lease generate significant impact on the prepayment probability (reduction of 21% and 75% for respectively a 1% increase in DSCR and when an agreement is signed.

Finally, if property supply elasticity rises up by one unit, the prepayment probability will be raised to more than three times. This reflects that borrowers in elastic supply area have stronger willingness to fully prepay in order to maximise their profits because they can predict to a less degree of uncertainty than in supply constrained markets.

Tables 5.9 and 5.10 report the estimation results for the second stage: default vs restructuring, prepayment in cash vs defeasance, and curtailment vs partial defeasance. Model M4a shows how a borrower's choice between the two denial obligation options are affected by mortgage and collateral related terms. LTV ratios, time to maturity and balloon payment rate have minimal impact, while a 1% change in negative amortization rate and mortgage rate significantly affect the likelihood of restructuring vs default (respectively by 49% and 42%). Importantly, interest only mortgages show a probability which is three times bigger due to the high level of outstanding loan balance present at the time of exercising the option in comparison with constant payment mortgages. Moreover, if a mortgage contract includes a cross-collateralization covenant, the likelihood of restructuring relative to default is 23% higher. As far as collateral related terms are concerned, increasing the DSCR by 1% increases the likelihood of restructuring by 47%.

Furthermore, property supply constraints also exert a significant impact and a 73% reduction in the probability of restructuring is obtained when the supply elasticity increases by one unit. As the restructuring becomes less likely to occur for a mortgage collateralized with an office building in supply elastic markets, we infer that lenders probably expect a greater bounce of property prices in supply inelastic markets and they are therefore willing to modify the loan structure for temporary insolvent borrowers more than for collateral assets in supply elastic markets (where lenders do not expect a significant rebound).

Table 5.9: Two-Stage Model (Winsorized): The Second Stage - Logit Model Results - Coefficients

Independent Variables	**M1a**	**M1b**	**M1c**	**M2a**	**M2b**	**M2c**	**M3a**	**M3b**	**M3c**	**M4a**	**M4b**	**M4c**
$LTV_{m,t}$	-0.079***	0.003	0.128***	-0.079***	0.003	0.128***	-0.048***	0.003*	0.127***	-0.072***	0.003*	0.128***
	(0.002)	(0.002)	(0.021)	(0.002)	(0.002)	(0.021)	(0.002)	(0.002)	(0.021)	(0.002)	(0.002)	(0.021)
$TTM_{m,t}$	0.0002	-0.0007***	-0.002	0.0002	-0.0007***	-0.002	-9.48×10^{-6}	-0.0007***	-0.002	0.0001	-0.0006***	-0.002
	(0.0003)	(0.0002)	(0.002)	(0.0003)	(0.0002)	(0.002)	(0.0003)	(0.0002)	(0.002)	(0.0003)	(0.0002)	(0.002)
$BPR_{m,t}$	-0.004***		-0.017***	-0.004***		-0.017***	-0.004***		-0.017***	-0.004***		-0.017***
	(0.0006)		(0.005)	(0.0006)		(0.005)	(0.0006)		(0.005)	(0.0006)		(0.005)
$NAR_{m,t}$	-0.682***		21.785*	-0.682***		21.908*	-0.642***		21.565*	-0.670***		21.704*
	(0.092)		(12.636)	(0.092)		(12.704)	(0.092)		(12.620)	(0.092)		(12.686)
$MR_{m,t}$	-0.610***	0.225***	0.610***	-0.610***	0.224***	0.605***	-0.359***	0.228***	0.608***	-0.539***	0.227***	0.603***
	(0.024)	(0.015)	(0.171)	(0.024)	(0.015)	(0.172)	(0.022)	(0.015)	(0.171)	(0.024)	(0.016)	(0.171)
MT_m	1.096***	-0.625***	0.894***	1.097***	-0.625***	0.898***	1.095***	-0.627***	0.879***	1.099***	-0.626***	0.884***
	(0.020)	(0.034)	(0.208)	(0.020)	(0.034)	(0.209)	(0.020)	(0.034)	(0.208)	(0.020)	(0.034)	(0.209)
CC_m	0.201***	0.430***		0.2003***	0.431***		0.198***	0.430***		0.205***	0.430***	
	(0.060)	(0.062)		(0.060)	(0.062)		(0.060)	(0.062)		(0.060)	(0.062)	
$PPYM_{m,t}$	-0.002			-0.001			0.009			0.001		
	(0.082)			(0.081)			(0.076)			(0.080)		
$DSCR_{m,t}$	0.343***	0.111**	-1.500***	0.342***	0.111**	-1.501***	0.506***	0.119**	-1.470***	0.383***	0.118***	-1.471***
	(0.035)	(0.052)	(0.297)	(0.035)	(0.052)	(0.296)	(0.034)	(0.052)	(0.297)	(0.035)	(0.052)	(0.296)
$PA_{m,t}$	0.005***	0.006***	0.021***	0.005***	0.006***	0.021***	0.005***	0.006***	0.021***	0.005***	0.006***	0.021***
	(0.0007)	(0.0006)	(0.004)	(0.0007)	(0.0006)	(0.004)	(0.0007)	(0.0006)	(0.005)	(0.0007)	(0.0006)	(0.004)
$OR_{m,t}$	0.015***	0.016***	-0.056***	0.015***	0.016***	-0.056***	0.016***	0.015***	-0.055***	0.016***	0.015***	-0.055***
	(0.0008)	(0.001)	(0.009)	(0.0008)	(0.001)	(0.009)	(0.0008)	(0.001)	(0.009)	(0.0008)	(0.001)	(0.009)
CTL_m	-1.229	3.801***		-1.225	3.798***		-1.135	3.801***		-1.025	3.798***	
	(1.024)	(1.320)		(1.024)	(1.319)		(1.024)	(1.318)		(1.026)	(1.317)	
PSE_m	-1.359***	1.837***	-13.273***	-1.355***	1.844***	-13.498***	-1.151***	1.827***	-13.071***	-1.291***	1.834***	-13.292***
	(0.210)	(0.237)	(1.906)	(0.210)	(0.237)	(1.925)	(0.209)	(0.238)	(1.897)	(0.212)	(0.238)	(1.916)
$\Delta PAR_{m,t-3}$				-0.001	-0.001	0.023				-0.001	-0.001	0.023
				(0.001)	(0.001)	(0.017)				(0.001)	(0.001)	(0.017)
ΔFMR_{t-3}							-0.008	1.167	5.779**	-0.072	1.166	5.787**
							(0.131)	(0.872)	(2.925)	(0.123)	(0.872)	(2.932)
ΔITY_{t-3}							0.001	-0.023	-0.119	0.006	-0.023	-0.119
							(0.014)	(0.023)	(0.077)	(0.013)	(0.023)	(0.077)
Constant	6.449***	-6.224***	-5.286**	6.444***	-6.219***	-5.170**	0.606	-3.019	10.461	4.047***	-3.016	10.603
	(0.983)	(0.465)	(2.526)	(0.983)	(0.465)	(2.528)	(0.384)	(2.622)	(8.987)	(0.374)	(2.622)	(9.005)
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Log Likelihood	-20146	-16234	-306	-20140	-16227	-305	-20016	-16132	-304	-19825	-16126	-303
LR Chi Square	14667	11813	467	14665	11802	468	14036	11674	456	14406	11663	457
Observations	47512	36739	1652	47500	36728	1652	46731	36382	1626	46719	36371	1626

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $OE_{m,t}$: Office Using Employment in MSA, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
The outcomes of M1a, M2a, M3a and M4a are default=0 and restructured=1. The outcomes of M1b, M2b, M3b and M4b are prepaid in cash=0 and defeased=1. The outcomes of M1c, M2c, M3c and M4c are curtailed=0 and partially defeased=1.
Figures in parentheses are standard errors.
***, ** and * represent significant level at 1%, 5%, 10%.

Table 5.10: Two-Stage Model (Winsorized): The Second Stage - Logit Model Results - Odd Ratios

Independent Variables	**M1a**	**M1b**	**M1c**	**M2a**	**M2b**	**M2c**	**M3a**	**M3b**	**M3c**	**M4a**	**M4b**	**M4c**
$LTV_{m,t}$	0.924***	1.003	1.136***	0.924***	1.003	1.137***	0.954***	1.003*	1.136***	0.930***	1.003*	1.136***
$TTM_{m,t}$	1.0002	0.9993***	0.998	1.0002	0.9993***	0.998	1.000	0.9993***	0.998	1.0001	0.9994***	0.998
$BPR_{m,t}$	0.996***		0.983***	0.996***		0.996***	0.996***		0.983***	0.996***		0.983***
$NAR_{m,t}$	0.505***		2.89×10^{9}*	0.505***		3.27×10^{9}*	0.526***		2.32×10^{9}*	0.511***		2.67×10^{9}*
$MR_{m,t}$	0.543***	1.252***	1.841***	0.543***	1.251***	1.832***	0.698***	1.256***	1.837***	0.583***	1.255***	1.828***
MT_{m}	2.993***	0.535***	2.445***	2.995***	0.535***	2.455***	2.989***	0.534***	2.409***	3.001***	0.534***	2.420***
CC_{m}	1.222***	1.537***		1.222***	1.538***		1.219***	1.537***		1.228***	1.538***	
$PPYM_{m,t}$	0.998			0.999			1.009			1.001		
$DSCR_{m,t}$	1.409***	1.118**	0.223***	1.408***	1.117**	0.223***	1.658***	1.126**	0.230***	1.466***	1.125**	0.230***
$PA_{m,t}$	1.005***	1.006***	1.022***	1.005***	1.006***	1.021***	1.005***	1.006***	1.022***	1.005***	1.006***	1.021***
$OR_{m,t}$	1.015***	1.016***	0.946***	1.015***	1.016***	0.945***	1.017***	1.016***	0.947***	1.016***	1.016***	0.946***
CTL_{m}	0.293	44.766***		0.294	44.626***		0.321	44.732***		0.359	44.599***	
PSE_{m}	0.257***	6.276***	1.72×10^{-6}***	0.258***	6.324***	1.37×10^{-6}***	0.316***	6.214***	2.1×10^{-6}***	0.275***	6.260***	1.69×10^{-6}***
$\Delta PAR_{m,t-3}$				0.999	0.999	1.023				0.999	0.999	1.023
ΔFMR_{t-3}							0.992	3.212	323.425**	0.930	3.210	326.109**
ΔITY_{t-3}							1.001	0.978	0.888	1.006	0.978	0.888
Constant	632.359***	0.002***	0.005**	629.184***	0.002***	0.006**	1.833	0.049	34938	57.206***	0.049	40242
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_{m}: Mortgage Type (Interest Only), CC_{m}: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_{m}: Credit Tenant Lease, PSE_{m}: Property Supply Elasticity, $OE_{m,t}$: Office Using Employment in MSA, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_{t}: Fixed Rate Mortgage Market Rate.
The outcomes of M1a, M2a, M3a and M4a are default=0 and restructured=1. The outcomes of M1b, M2b, M3b and M4b are prepaid in cash=0 and defeased=1. The outcomes of M1c, M2c, M3c and M4c are curtailed=0 and partially defeased=1.
***, ** and * represent significant level at 1%, 5%, 10%.

As far as the decision between prepayment in cash and defeasance (model M4b) is concerned, a 1% change in mortgage rates, interest-only mortgages and the presence of cross-collateralization respectively determine an increase of 26% and reduction of 47% and 54% in the likelihood of defeasance. Similar results are found for this second pair of competing options for collateral terms: a 1% increase in DSCR and the existence of an underlying credit tenant lease increases defeasance occurrence by respectively 13% and more than 40 times.
Looking at property supply constraints, one unit increase in elasticity raises the probability of defeasance by five times, showing that mortgages are more likely and significantly to be defeased than prepaid in cash if the collateral is an office property in supply elastic markets. In fact lenders more likely offer defeasance provisions for mortgages collateralized in supply elastic market as property prices remain reasonably stable and the risk differential between holding Treasury securities and properties is reduced significantly.
In the second stage model, capturing changes in property absorption rates and market interest rates as well as Treasury yield does not bring any statistically significant changes in estimated results. Therefore we conclude that property supply factors are more important than demand side factors in explaining behaviour of early mortgage terminations. Our results confirm the research hypothesis and suggest the use of relaxation vs. tightening property supply constraints as a further risk management tool to control the exercise of mortgage termination options.

5.6.2 Partial Prepayment Behaviour

For some mortgage contracts, both partial prepayment (equivalent to curtailment) and partial defeasance are allowed. Therefore, we examine the partial prepayment behaviour of borrowers, adding to a literature that overlooked at this important decision so far.

Overall, the estimated results in the first stage are reported in the tables 5.7 and 5.8 and they are consistent with theoretical expectations for partial prepayment. Across mortgage terms in the first stage, negative amortization rate, mortgage rate, mortgage type and cross collateralization reveal the greatest impact on partial prepayment, with the likelihood of partial prepayment increasing by 50% for IOMs as borrowers are more likely capable of making extra payments than CPM borrowers, especially if they further reduce the outstanding loan balance and hence periodical payments with a partial prepayment. A 1% increase in mortgage rate raises the likelihood of partial prepayment by 81%, while A 1% increase in negative amortization rate and the presence of a cross-collateralization covenant reduce the likelihood of partial prepayment by 92% and 58% respectively. A cross-collateralization implies the ownership of at least two assets and at least two mortgages guaranteed by both assets. Therefore a higher amount of mortgage payments can insist on the collateral and borrowers may be less capable of making extra payments lowering the probabilities of partial prepayments.

In contrast, we find moderate and positive (but statistically insignificant) impact of LTV ratios and prepayment penalty / yield maintenance (1% change leads to respectively 2% and 4% probability shift) on the likelihood of partial prepayment. This finding reflects the potential substitution between full and partial prepayment. As prepayment penalties are extremely high for full prepayment, borrowers still look for opportunities to reduce interest costs and turn to partial prepayment where only a portion of prepayment penalty / yield maintenance is charged and found to be positively related to partial prepayment. Among collateral related terms, DSCR and collateral underlying property supply elasticities affect the likelihood of partial prepayment increasing it by respectively 123% with a 1% increase in DSCR (i.e. increasing incomes encourage partial prepayment for lowering debt level) and a reduction of 48% with a one unit increase in supply elasticity. Greater uncertainty of property market in supply inelastic area encourage partial prepayment instead of full prepayment, as borrowers need more time to observe the market trend and have less confidence to cash in maximized profits by full prepayment. For mortgage market rates (see model M4), the positive impact on partial prepayment is also very significant. Mortgage market rates positively correlate with property prices, and hence rising market rates are associated with upward trends in property prices. This encourages partial prepayment.
Finally, we analyze the likelihood of partial defeasance relative to curtailment (second stage) - see tables 5.9 and 5.10. Based on model M4c, a 1% increase in mortgage rates increases the probability by 83%, while its sensitivity to changes in negative amortization rates is even higher. IOMs show probability of partial defeasance increased by 142% and, among collateral related terms, DSCR and property supply elasticities show significant impact on the probability of partial defeasance (respectively 77% and 100% reduction for 1% or 1 unit increase). Borrowers with lower debt service and hence lower debt levels may play a more important role in lowering the incentives to further reduce debt by partial defeasance. Finally, as treasury yields reflecting the cost of defeasance, we find a short term increase in Treasury yields reduces the likelihood of partial defeasance

by 11% to pre-empt rises in future interest rates making defeasance less attractive.

5.6.3 Probabilities of Early Mortgage Termination and Partial Prepayment

Table 5.11 summarizes our estimated probabilities of four types of early mortgage termination and two types of partial prepayment options. We employ model M4 to estimate the probabilities, but similar results are also confirmed using other models. Firstly, we estimate the probabilities of denying obligations and full prepayments as well as partial prepayments employing the first-stage model and the conditional probabilities of four types of early mortgage termination and two types of partial prepayments from the second-stage models - i.e. P(default | denying obligations), P(restructuring | denying obligations), P(cash settlement | prepayment), P(defeasance | prepayment), P(curtailment | partial prepayment) and P(partial defeasance | partial prepayment). Secondly, we multiply the probabilities of denying obligations with the probability of default (restructuring), conditional to the probability of obligation denial from the fist stage to compute the probabilities of default and denial. For full and partial prepayments, we take a similar approach and estimate the probabilities by multiplying probabilities of full prepayment and cash settlement, full prepayment and defeasance, as well as the probability of partial prepayment and curtailment and the probability of partial prepayment and partial defeasance.

For early mortgage termination, the estimates show that default is more likely to occur relative to restructuring and a cash settlement is more likely to occur than defeasance. For denying obligations, lenders may not be willing to offer favourable restructuring plans with significant adjustments in interest rates and loan maturities, and borrowers choose to default. Considering lenders' decisions, the probability of default is higher than mortgage restructuring. However, we suggest that lenders consider an optimization process to set up covenants in mortgage contracts for their own risk management and subsequently obtain benefits through restructuring.

For partial prepayment, probabilities are much lower than those of early mortgage termination in full. Borrowers prefer to fully prepay and curtailment is ten times more likely occurs than partial defeasance as the latter might be perceived as more complicated than paying in cash.

To conclude, we suggest regulators and policymakers to consider relaxation and tightening of property supply constraints as a potential risk management tool to control the exercise of early mortgage termination options in the first stage (i.e. higher property supply elasticities are associated with much lower probabilities of denying obligations although higher likelihood of full prepayment is found). In the second stage, default options and defeasance options in property supply elastic markets are more frequently exercised. Lenders and policymakers should carefully consider the level of collateral underlying property supply elasticities and precisely adjust regulatory constraints so that early mortgage terminations can be reduced or lenders and borrowers can make mutually optimal solutions to early mortgage termination particularly mortgage default based on simulations obtained in our theoretical framework.

Table 5.11: Summary of Estimated Probabilities of Early Mortgage Termination and Partial Prepayment (Winsorized)

Probability	**Mean**	**S.D.**	**Min.**	**Max.**	**Skewness**	**Kurtosis**
P(Denying Obligations and Default)	0.037	0.107	0	0.969	4.516	25.946
P(Denying Obligations and Restructuring)	0.013	0.042	0	0.992	6.233	57.511
P(Prepayment and Cash Settlement)	0.183	0.125	0	0.711	0.685	2.642
P(Prepayment and Defeasance)	0.111	0.127	0	0.732	1.825	6.366
P(Partial Prepayment and Curtailment)	0.003	0.007	0	0.293	10.681	197.0996
P(Partial Prepayment and Partial Defeasance)	0.0003	0.001	0	0.059	23.389	976.696

Notes:
We estimate P(Denying Obligations) and P(Prepayment) as well as P(Partial Prepayment) by the first stage model (M4) and then multiple the conditional probabilities estimated by the second stage models (M4a and M4b as well as M4c) to compute the probabilities: P(Denying Obligations and Default), P(Denying Obligations and Restructuring), P(Prepayment and Cash Settlement), P(Prepayment and Defeasance), P(Partial Prepayment and Curtailment) and P(Partial Prepayment and Partial Defeasance).

5.6.4 Robustness Check

Firstly, we ignore partial prepayment and conduct the analysis solely for early mortgage termination in full. We summarize the main results of the first stage in tables 5.12 and 5.13. Consistent with our main findings, an increase in property supply elasticity significantly reduces the likelihood of obligation denial but increases the probability of full prepayments.

Tables 5.14 and 5.15 report the main results of the second stage without partial prepayment. Default and defeasance are more likely to occur when underlying property markets are more supply elastic and we find confirmation of our main conclusions.

Secondly, we focus on the impact of collateral underlying property supply elasticities on early termination option. As supply constraints are mainly due to physical land unavailability and regulatory constraints, we also consider other two measures of property supply elasticity available constructed in residential markets for each of the aforementioned criteria: Saiz (2010[149]) measure of land unavailability (i.e. undevelopable area corresponding to steep slopes, oceans, lakes, wetlands, and other water features) and the Wharton residential urban land regulation index developed by Gyourko et al. (2008[99]) through a survey to US municipalities. We replace our estimated office supply elasticities with these two series to empirically test the consistency of our results. Both elasticity proxies show a positive and negative relationship between supply elasticity and the likelihood of respectively denying obligations and prepayment. Both these findings violate our theoretical expectations and we then conclude that office supply elasticities cannot be directly proxied with measures from the residential market, also because land availability and regulations between the two sector may differ within the same MSA (e.g. different location for housing stock and the CBD market, existence of sector-specific zoning, etc.).

Table 5.12: Two-Stage Model: The First Stage - Multinomial Logit Model Results - Coefficients (Winsorized, Exclude Partial Prepayment)

Independent Variables	R1		R2		R3		R4	
	Def or Res	Prep or Dfes	Def or Res	Prep or Dfes	Def or Res	Prep or Dfes	Def or Res	Prep or Dfes
$LTV_{m,t}$	0.126***	0.007***	0.127***	0.007***	0.126***	0.007***	0.130***	0.008***
	(0.001)	(0.0004)	(0.001)	(0.0004)	(0.001)	(0.0004)	(0.001)	(0.0004)
$TTM_{m,t}$	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
$BPR_{m,t}$	0.004***	-0.018***	0.004***	-0.018***	0.004***	-0.018***	0.004***	-0.018***
	(0.0002)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0001)
$NAR_{m,t}$	-1.057***	0.088	-1.054***	0.088	-1.056***	0.088	-1.041***	0.088
	(0.167)	(0.079)	(0.168)	(0.079)	(0.167)	(0.079)	(0.167)	(0.079)
$MR_{m,t}$	0.493***	0.494***	0.495***	0.494***	0.493***	0.494***	0.499***	0.497***
	(0.009)	(0.004)	(0.009)	(0.004)	(0.009)	(0.004)	(0.009)	(0.004)
MT_m	0.614***	-0.229***	0.615***	-0.229***	0.614***	-0.229***	0.612***	-0.228***
	(0.008)	(0.007)	(0.008)	(0.007)	(0.008)	(0.007)	(0.008)	(0.007)
CC_m	0.190***	0.164***	0.191***	0.164***	0.189***	0.164***	0.190***	0.164***
	(0.028)	(0.020)	(0.028)	(0.020)	(0.028)	(0.020)	(0.028)	(0.020)
$PPYM_{m,t}$	-0.031	-236.371	-0.031	-282.505	-0.031	-236.999	-0.030	-476.308
	(0.034)	(5199.79)	(0.034)	(9628.02)	(0.034)	(5242.32)	(0.034)	(121428)
$DSCR_{m,t}$	-0.551***	-0.265***	-0.569***	-0.268***	-0.551***	-0.265***	-0.625***	-0.273***
	(0.017)	(0.010)	(0.017)	(0.010)	(0.017)	(0.010)	(0.017)	(0.010)
$PA_{m,t}$	-0.002***	0.007***	-0.002***	0.007***	-0.002***	0.007***	-0.002***	0.007***
	(0.0003)	(0.0002)	(0.0003)	(0.0002)	(0.0003)	(0.0002)	(0.0003)	(0.0002)
$OR_{m,t}$	-0.037***	0.017***	-0.037***	0.017***	-0.037***	0.017***	-0.037***	0.016***
	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0003)	(0.0004)
CTL_m	-0.335***	-1.409***	-0.327***	-1.409***	-0.335***	-1.409***	-0.312***	-1.409***
	(0.118)	(0.099)	(0.117)	(0.099)	(0.118)	(0.099)	(0.118)	(0.099)
PSE_m	-1.026***	1.495***	-1.010***	1.496***	-1.025***	1.495***	-1.027***	1.497***
	(0.089)	(0.066)	(0.089)	(0.066)	(0.089)	(0.066)	(0.089)	(0.066)
$\Delta PAR_{m,t-3}$			-0.001***	-0.0006**			-0.001***	-0.0006**
			(0.0003)	(0.0003)			(0.0003)	(0.0003)
ΔFMR_{t-3}					-0.323	-1.887	-0.323	-1.887
					(72.376)	(10.418)	(72.618)	(10.348)
Constant	-8.584	4.070	-8.590	4.068	-11.097	-10.582	-11.156	-10.578
	(350.798)	(50.421)	(347.531)	(50.237)	(211.237)	(30.406)	(211.942)	(30.202)
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y
BIC	728608		728330		728578		727570	
Log Likelihood	-361260		-361108		-361259		-360741	
LR Chi Square	271901		271909		271903		272642	
Observations	987932		987552		987932		987552	

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
Def, Res, Prep and Dfes mean Default, Restructured, Prepaid and Defeased.
Figures in parentheses are standard errors.
***, ** and * represent significant level at 1%, 5%, 10%.

Table 5.13: Two-Stage Model: The First Stage - Multinomial Logit Model Results - Relative Risk Ratio (Winsorized, Exclude Partial Prepayment)

Independent Variables	**R1**		**R2**		**R3**		**R4**	
	Def or Res	**Prep or Dfes**	**Def or Res**	**Prep or Dfes**	**Def or Res**	**Prep or Dfes**	**Def or Res**	**Prep or Dfes**
$LTV_{m,t}$	1.135***	1.007***	1.136***	1.007***	1.135***	1.007***	1.139***	1.008***
$TTM_{m,t}$	0.995***	0.995***	0.995***	0.995***	0.995***	0.995***	0.995***	0.995***
$BPR_{m,t}$	1.004***	0.982***	1.004***	0.982***	1.004***	0.982***	1.004***	0.982***
$NAR_{m,t}$	0.348***	1.092	0.349***	1.092	0.348***	1.092	0.353***	1.092
$MR_{m,t}$	1.637***	1.638***	1.641***	1.640***	1.637***	1.638***	1.648***	1.644***
MT_m	1.848***	0.795***	1.849***	0.795***	1.849***	0.795***	1.844***	0.796***
CC_m	1.209***	1.179***	1.211***	1.178***	1.208***	1.178***	1.210***	1.178***
$PPYM_{m,t}$	0.970	0	0.970	0	0.970	0	0.970	0
$DSCR_{m,t}$	0.576***	0.767***	0.566***	0.765***	0.577***	0.767***	0.535***	0.761***
$PA_{m,t}$	0.998***	1.007***	0.998***	1.007***	0.998***	1.007***	0.998***	1.007***
$OR_{m,t}$	0.964***	1.017***	0.964***	1.017***	0.964***	1.017***	0.963***	1.017***
CTL_m	0.716***	0.244***	0.721***	0.244***	0.715***	0.244***	0.732***	0.244***
PSE_m	0.358***	4.458***	0.364***	4.462***	0.359***	4.459***	0.358***	4.470***
$\Delta PAR_{m,t-3}$			0.999***	0.999**			0.999***	0.999**
ΔFMR_{t-3}					0.724	0.152	0.724	0.152
Constant	0.0002	58.532	0.0002	58.436	0.00002	0.00003	0.00001	0.00003
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
Def, Res, Prep and Dfes mean Default, Restructured, Prepaid and Defeased.
***, ** and * represent significant level at 1%, 5%, 10%.

Table 5.14: Two-Stage Model: The Second Stage - Logit Model Results - Coefficients (Winsorized, Exclude Partial Prepayment)

Independent Variables	**R1a**	**R1b**	**R2a**	**R2b**	**R3a**	**R3b**	**R4a**	**R4b**
	Def=0 & Res=1	**Prep=0 & Dfes=1**	**Def=0 & Res=1**	**Prep=0 & Dfes=1**	**Def=0 & Res=1**	**Prep=0 & Dfes=1**	**Def=0 & Res=1**	**Prep=0 & Dfes=1**
$LTV_{m,t}$	-0.079***	0.003	-0.079***	0.003	-0.079***	0.003	-0.079***	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$TTM_{m,t}$	0.0002	-0.0007***	0.0002	-0.0007***	0.0002	-0.0007***	0.0002	-0.0007***
	(0.0003)	(0.0002)	(0.0003)	(0.0002)	(0.0003)	(0.0002)	(0.0003)	(0.0002)
$BPR_{m,t}$	-0.004***		-0.004***		-0.004***		-0.004***	
	(0.0006)		(0.0006)		(0.0006)		(0.0006)	
$NAR_{m,t}$	-0.682***		-0.682***		-0.682***		-0.682***	
	(0.092)		(0.092)		(0.092)		(0.092)	
$MR_{m,t}$	-0.610***	0.225***	-0.610***	0.224***	-0.610***	0.225***	-0.610***	0.224***
	(0.024)	(0.015)	(0.024)	(0.015)	(0.024)	(0.015)	(0.024)	(0.015)
MT_m	1.096***	-0.625***	1.097***	-0.625***	1.096***	-0.625***	1.097***	-0.625***
	(0.020)	(0.034)	(0.020)	(0.034)	(0.020)	(0.034)	(0.020)	(0.034)
CC_m	0.201***	0.430***	0.200***	0.431***	0.201***	0.430***	0.200***	0.431***
	(0.060)	(0.062)	(0.060)	(0.062)	(0.060)	(0.062)	(0.060)	(0.062)
$PPYM_{m,t}$	-0.002		-0.001		-0.002		-0.001	
	(0.082)		(0.081)		(0.082)		(0.081)	
$DSCR_{m,t}$	0.343***	0.111**	0.342***	0.111**	0.343***	0.111**	0.342***	0.111***
	(0.035)	(0.052)	(0.035)	(0.052)	(0.035)	(0.052)	(0.035)	(0.052)
$PA_{m,t}$	0.005***	0.006***	0.005***	0.006***	0.005***	0.006***	0.005***	0.006***
	(0.0007)	(0.0006)	(0.0007)	(0.0006)	(0.0007)	(0.0006)	(0.0007)	(0.0006)
$OR_{m,t}$	0.015***	0.016***	0.015***	0.016***	0.015***	0.016***	0.015***	0.016***
	(0.0008)	(0.001)	(0.0008)	(0.001)	(0.0008)	(0.001)	(0.0008)	(0.001)
CTL_m	-1.229	3.801***	-1.225	3.798***	-1.229	3.801***	-1.225	3.798***
	(1.024)	(1.320)	(1.024)	(1.319)	(1.024)	(1.320)	(1.024)	(1.319)
PSE_m	-1.359***	1.837***	-1.355***	1.844***	-1.359***	1.837***	-1.355***	1.844***
	(0.210)	(0.237)	(0.210)	(0.237)	(0.210)	(0.237)	(0.210)	(0.237)
$\Delta PAR_{m,t-3}$			-0.001	-0.001			-0.001	-0.001
			(0.001)	(0.001)			(0.001)	(0.001)
ΔFMR_{t-3}					-0.090	-0.018	-0.090	-0.017
					(0.224)	(0.565)	(0.224)	(0.565)
Constant	6.449***	-6.223***	6.444***	-6.219***	5.800***	-6.274***	5.792***	-6.270***
	(0.983)	(0.465)	(0.983)	(0.465)	(0.750)	(1.430)	(0.750)	(1.430)
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y
Log Likelihood	-20146	-16234	-20140	-16227	-20146	-16234	-20140	-16227
LR Chi Square	14667	11813	14665	11802	14667	11813	14665	11802
Observations	47512	36739	47500	36728	47512	36739	47500	36728

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
Def, Res, Prep and Dfes mean Default, Restructured, Prepaid and Defeased.
Figures in parentheses are standard errors.
***, ** and * represent significant level at 1%, 5%, 10%.

Table 5.15: Two-Stage Model: The Second Stage - Logit Model Results - Odd Ratios (Winsorized, Exclude Partial Prepayment)

Independent Variables	**R1a** **Def=0 & Res=1**	**R1b** **Prep=0 & Dfes=1**	**R2a** **Def=0 & Res=1**	**R2b** **Prep=0 & Dfes=1**	**R3a** **Def=0 & Res=1**	**R3b** **Prep=0 & Dfes=1**	**R4a** **Def=0 & Res=1**	**R4b** **Prep=0 & Dfes=1**
$LTV_{m,t}$	0.924***	1.003	0.924***	1.003	0.924***	1.003	0.924***	1.003
$TTM_{m,t}$	1.0002	0.999***	1.0002	0.999***	1.0002	0.999***	1.0002	0.999***
$BPR_{m,t}$	0.996***		0.996***		0.996***		0.996***	
$NAR_{m,t}$	0.505***		0.505***		0.505***		0.505***	
$MR_{m,t}$	0.543***	1.252***	0.543***	1.251***	0.543***	1.252***	0.543***	1.251***
MT_m	2.993***	0.535***	2.995***	0.535***	2.993***	0.535***	2.995***	0.535***
CC_m	1.222***	1.537***	1.222***	1.538***	1.222***	1.537***	1.222***	1.538***
$PPYM_{m,t}$	0.998		0.999		0.998		0.999	
$DSCR_{m,t}$	1.409***	1.118**	1.408***	1.117**	1.409***	1.118**	1.408***	1.117**
$PA_{m,t}$	1.005***	1.006***	1.005***	1.006***	1.005***	1.006***	1.005***	1.006***
$OR_{m,t}$	1.015***	1.016***	1.015***	1.016***	1.015***	1.016***	1.015***	1.016***
CTL_m	0.293	44.766***	0.294	44.626***	0.293	44.766***	0.294	44.626***
PSE_m	0.257***	6.276***	0.258***	6.324***	0.257***	6.276***	0.258***	6.324***
$\Delta PAR_{m,t-3}$			0.999	0.999			0.999	0.999
ΔFMR_{t-3}					0.914	0.983	0.914	0.983
Constant	632.359***	0.002***	629.184***	0.002***	330.227***	0.002***	327.716***	0.002***
Fixed State Effects	Y	Y	Y	Y	Y	Y	Y	Y
Fixed Time Effects	Y	Y	Y	Y	Y	Y	Y	Y

Notes:
$LTV_{m,t}$: LTV ratio, $TTM_{m,t}$: Time to Maturity, $BPR_{m,t}$: Balloon Payment Ratio, $NAR_{m,t}$: Negative Amortization Rate, $MR_{m,t}$: Mortgage Rate, MT_m: Mortgage Type (Interest Only), CC_m: Cross Collateralization, $PPYM_{m,t}$: Prepayment Penalty & Yield Maintenance, $DSCR_{m,t}$: Debt Service Coverage Ratio, $PA_{m,t}$: Property Age, $OR_{m,t}$: Occupancy Rate, CTL_m: Credit Tenant Lease, PSE_m: Property Supply Elasticity, $PAR_{m,t}$: Property Absorption Rate in MSA, FMR_t: Fixed Rate Mortgage Market Rate.
Def, Res, Prep and Dfes mean Default, Restructured, Prepaid and Defeased.
***, ** and * represent significant level at 1%, 5%, 10%.

5.7 Conclusion

This research empirically examines the borrower's strategic choice in mortgage termination options. Following the theoretical framework, we have developed a two-stage empirical model using a multinomial logit model in the first stage and logit models in the second stage to analyze the likelihood of four types of early mortgage termination options: default vs restructuring and full prepayment in cash vs defeasance. Moreover, we also empirically estimate and model the likelihood of partial prepayment by adding an extra outcome in the first stage and a pair of competing options (i.e. curtailment vs partial defeasance) in the second stage. As far as we know, this represents the first study to simultaneously investigate these two pairs of mortgage termination options, to examine restructuring as a "competitor" to mortgage default, and to provide empirical evidence on causes of probabilities of restructuring relative to default and defeasance relative to prepayment in cash.

Based on our estimated probabilities, we show that default is more likely to occur than restructuring for obligation denial, while a cash settlement is more likely than defeasance for prepayment. In the first stage, mortgage rates, mortgage type (IOM), DSCR and credit tenant lease exert a significant impact on the decision to deny obligations or prepay. In the second stage, changing negative amortization rate, mortgage rate, mortgage type, cross-collateralization, DSCR and credit tenant lease are important factors on the decision of restructuring relative to defaulting, also favouring the choice of defeasance over payment in cash.

Moreover, we particularly emphasize the role of property supply constraints on early mortgage termination. One unit increase in property supply elasticity reduces the likelihood of denying obligations by 55% and increases the likelihood of prepayments by more than three times in the first stage, results consistent with theoretical expectations. In the second stage, an increase in property supply elasticity significantly lowers the probability of restructuring relative to default, but it increases the likelihood of defeasance relative to prepayment in cash.

This also represents the first attempt to empirically examine the partial prepayment behaviour. Introducing this new aspect of borrowers' choice, we show they act strategically. In supply constrained real estate markets, they perceive that a higher uncertainty in property prices may either lead to a further increase in prices or sharp fall if the market cycle turns. Therefore they tend to cash in a minimum gain from partial prepayment (likelihood is increased as elasticity decreases) but want to retain the opportunity of accessing further uplifts at the same time (and therefore the likelihood of full prepayment decreases). In supply inelastic property markets borrowers choose to curtail mortgages rather than to partially defease.

In conclusion, property supply constraints play a pivotal role in determining the likelihood of early mortgage termination behaviour, thus we should not ignore this important driving force in mortgage studies as they modify the mortgage risk borne by lenders. Therefore, regulators and policymakers should monitor the amount of lending to property supply constrained markets as a measure of risk exposure and use a relaxation or tightening of these constraints as an alternative risk management tool for mortgage markets to control the exercise of early termination options, and particularly default.

Chapter 6

Final Conclusion

This research examines the impact of collateral underlying property supply constraints on early termination options embedded in commercial mortgages. After introducing the motivation and overarching literature review related to our study, in Chapter Three we estimate supply elasticities of office markets in 42 Metropolitan Statistical Areas (MSA hereafter). Generally supply inelastic markets are analyzed using a search and matching model and cross-sectional differences are explained by differences in regulatory and geographical constraints. In Chapter Four, we build a two-stage theoretical model to price early termination options (default and prepayment) by installment option valuation approach. We conclude that tightening collateral underlying property supply constraints pushes up value of early mortgage termination options. Chapter Five combines the previous two chapters conducting an empirical analysis on the impact of real estate supply elasticities on early mortgage termination options. MSAs with less restrictive supply constraints see a more frequent exercise of prepayment options, especially through defeasance rather than cash but less frequent exercise of denial options. For partial prepayment, loosening collateral underlying property supply constraints reduces the likelihood of an exercise.

Significant Role of Collateral Underlying Property Supply Constraints
Collateral underlying property supply constraints play an important role in determining the degree of property market response to demand shocks. In Chapter Four we apply an installment option pricing model to compute gross and net option values of early mortgage termination options and find that tightening collateral underlying property supply constraints increases option values of default and prepayment (both one-sided and joint options). Our results are consistent with theoretical prediction, with one unit decrease in demand causing a more sig-

nificant drop in property prices in more supply constrained markets. Therefore, values of early mortgage termination options become larger as supply becomes more inelastic. In addition to zero values of mortgage default, early mortgage termination options are unlikely exercised in supply elastic markets. However, the empirical study in Chapter Five find that increasing property supply elasticity reduces the likelihood of mortgage default but rises the probability of prepayment. The relationship between property supply elasticity and prepayment risk is inconsistent with theoretical expectation in Chapter Four. This can be explained by the existence of partial prepayment. Greater uncertainty in volatile property markets in supply inelastic area stimulate partial prepayment rather than full prepayment as borrowers act strategically by cashing in a fixed gain of the equity surplus in the partial prepayment, but decide to keep the option open on the remaining balance for potential further uplifts. As far as mortgage default is generally more concerned, controlling supply constraints could be an alternative risk management tool for mortgage markets. Even if we acknowledge the inelastic nature of real estate markets, we also find support for risk reduction via shifts in supply constraints.

Contribution to Related Research Area

In the first part of our research, we estimate US office supply elasticities at the MSA level. This represents the first empirical study to provide a precise estimation of office supply elasticities by employing a search and matching process in a simultaneous equation system. Our results are highly correlated with housing supply elasticities and constraint indices estimated by other scholars - Green et al. (2005 [92]), Gyourko et al. (2008 [99]), Saks (2008 [150]), Saiz (2010 [149]), Wheaton et al. (2014 [176]). As we distinguish vacancy into three types (i.e. cyclical, frictional and structural) by transferring concepts from labour economics, the equilibrium conditions are also determined by frictional and structural vacancies. Our findings show that in equilibrium demand equals supply after deducting both frictional and structural vacancies and we therefore shed light upon the equilibrium conditions required to model the pricing process.

Furthermore, we develop an installment option pricing model to valuate mortgage termination options. We basically make three contributions to mortgage studies. First, existing studies (Epperson et al. 1985 [65], Kau et al. 1992 [114]) mainly analogize mortgage default and prepayment as a collection of European put options and American call options respectively. However, they do not consider the stream of mortgage payments. In light of this, we revise the option analogy for pricing early mortgage termination. The early terminations should be analogous to American continuous installment options equipped with straddle or strangle payoff as options keep alive when scheduled mortgage payments as installments are made and borrowers can exercise early termination options anytime. Second, differently from extant works, we do not simply assume a log normal property price process - Kau et al. (1987 [112], 1992 [114], 1995 [111]), Ambrose and Capone (1998[11]) - and also include collateral underlying property supply constraints. This helps to capture property market dynamics into mortgage risk pricing models. Third, we capture execution costs (i.e. bankruptcy costs for mortgage default and prepayment penalties for prepayment) in the option pricing model by adding them to strike prices of underlying options. It is the first study to estimate implicit bankruptcy costs and include in mortgage risk models. We show that tightening property supply constraints increases option values whatever execution costs are considered. Thus, we argue that controlling supply constraints may lead to change in option exercise and can then be used to manage risks in mortgage markets.

Finally, we provide empirical evidence of the impact collateral underlying property supply constraints have on early mortgage terminations in the third main paper of this thesis (Chapter Five). We simultaneously investigate four types of early mortgage termination options (i.e. default, restructuring, prepayment in cash and defeasance) for the first time using the two-stage model. In the first stage, we find that one unit increase in property supply elasticity reduces the likelihood of denying obligations by 55% but increases the probability of prepayments by more than three times. In the second stage, an increase in property supply elasticities significantly lowers the probabilities of restructuring relative to mortgage default while it increases the probabilities of defeasance relative to prepayment in cash. Moreover, this study represents the first empirical research to investigate partial prepayment behaviour in commercial mortgage markets. We show that real estate markets becoming more elastic reduce the likelihood of partial prepayments and therefore, loosening property supply constraints reduces the incentives to deny obligations and partially prepay.

Limitations of the Study

Although we offer several contributions to the research field of commercial real estate market dynamics and early mortgage termination options, a few limitations related to data issues and modelling should also be acknowledged. First, in Chapter Three we identify "economic mismatch" by using data called "available but occupied stock". The data series starts from the first quarter of 2005, as data prior to 2005 is unavailable. Studies about housing cycle and housing supply constraints (e.g. Green et al. 2005 [92], Glaeser et al. 2008 [87], Wheaton et al. 2014 [176] and Hilber et al. 2016[105]) usually cover more than 20 years of data, but they are mostly in annual basis. Although we cover 11 year of data, quarterly basis is captured so that the time span is sufficient for estimating office supply elasticity. Whatsoever, if more historical data were available, we would be able to have a better understanding of changes in search and matching process in office markets.

Second, we were able to estimate structural vacancy but as far as the frictional component of the natural vacancy rate was concerned, we were only able to model the probability of its occurrence only in chapter three as there are no office renovation data proxying frictional vacancy. Although we do not estimate frictional vacancy, a finding by alternatively modelling the probability of frictional vacancy is insightful that economic mismatch is lower when refurbishment options are more likely to be exercised.

Third, as MSA level data on construction costs for commercial real estate are not available, we have an alternative approach by proxying this measure with operating expenses in Chapter Three and check the robustness of our results using residential construction costs under the assumption that costs for the two property uses are highly correlated.

Fourth, theoretical relationships between property supply elasticity and prepayment risk in Chapter Four is inconsistent with related empirical findings in Chapter Five. This may be due to the fact that we do not consider the alternative to full prepayment which is partial prepayment in the theoretical model. However, partial prepayment modelling is different from the models for pricing early mortgage termination options (Taleizadeh et al. 2013 [160]), we cannot simply extend the installment option pricing model to describe partial prepayment behaviour. Thus, the interaction between full and partial prepayment varied by collateral underlying property supply constraints cannot be modelled which is the weakness of our theoretical model.

Finally, we only have access to individual loan level data of securitized mortgages to investigate the impact of collateral underlying property supply constraints on early mortgage termination options in Chapter Five. There may be selection bias if we only cover securitized mortgages. If bank-held or insurance company-held loans were to be used for analysis, we may have further insight on this relationship considering differences in loan terms that likely-to-be securitised mortgage products have even though similar conclusions about competing risk are drawn based on securitized and unsecuritized mortgages (Ambrose et al. 2003 [15] and Ciochetti and Shilling 2013 [43]).

Policy Implication

In the aftermath of the Global Financial Crisis, the Dodd Frank Act was passed and the Federal Reserve started to require banks to be subject to more regular stress tests. In fact, in early 2018, the Federal Reserve conducted a stress test where a significant decline in commercial real estate prices (i.e.15%) was assumed. This reflects the awareness of possible negative shocks in commercial real estate markets which adversely affect commercial mortgage markets. When the Dodd Frank Act was intended to substantially reform the securitization process with focus on aligning the incentives of the securitizer of the loans and the bondholders, the Act changed the current risk transfer model for commercial mortgage backed securities (CMBS) by launching a new risk retention regulation in the end of 2016. The company doing the securitization is required to retain 5 percent of the risk for a period of five years. Underwriting standards in commercial mortgage markets are expected to tighten by approving less interest only mortgages or lowering leverage.

As far as credit risk of CMBS and commercial mortgage markets are concerned, we would suggest policymakers an approach for enhancing preciseness of forecasting the commercial real estate markets which are the main source of credit risk of CMBS and commercial mortgage markets. Our estimations of office supply elasticities in Chapter Three can help policymakers to more precisely forecast the movements in commercial real estate prices, and be used within a stress test framework, for example by measuring the exposure to more supply inelastic markets and allow for cross-sectional differences in the impact of possible demand shocks (i.e. banks lending to more elastic markets may suffer less than others). Furthermore, policymakers can consider adjustments in regulations in land or real estate markets to control mortgage market risks and monitoring financial markets as the related regulations determine tightness of property supply constraints.

Moreover, the Federal Reserve has launched a new metric to financial institutions to manage operational risk. The supplementary leverage ratio is computed as the ratio between a financial institution's tier 1 capital and its total leverage exposure, which includes all on-balance-sheet assets and several off-balance-sheet exposures. Financial institutions debated the fairness of such measure which also include risky commercial mortgages. As property supply elasticities are not considered in risk management models, cross-sectional differences of risks in commercial mortgage markets among MSAs are yet to be included. We therefore suggest the introduction of property supply constraints into the property price process to infer the impact of geographic variation of mortgage lending and adjust this metrics to reflect such differences which affect the operational risk of financial institutions.

Policymakers are able to capture property supply elasticities into their risk management models given that related property supply elasticities have been estimated. For office markets, we have already made the contribution by estimating office supply elasticities. Policymakers can directly refer to our work and develop the property supply elasticity adjusted credit risk management model. For other commercial real estate markets, policymakers can offer the related data to academic or industry professionals for developing econometric models for estimating supply elasticities of different commercial real estate markets. Then, after policymakers obtain all information of estimated property supply elasticities, they can precisely manage credit risk of CMBS and commercial mortgage markets as well as operational risk of financial institutions.

Future Research Direction

Beyond this thesis, we can extend our theoretical option pricing model to value mortgage restructuring. This may involve complex assumptions such as time varying boundary conditions. We intend to offer insight of measuring the likelihood of restructuring and risk management on mortgage default. Besides, we can construct the option pricing model with the assumption of incomplete markets and simulate the impact of property supply constraints on mortgage risk. This potentially helps to reinforce our suggestion of the possibility to control collateral underlying property supply constraints to manage mortgage market risk effectively.

As far as early mortgage terminations are concerned, we could also explore the effectiveness and performance of mortgage restructuring by tracking the loan status after the restructuring process, as well as the likelihood of full prepayments for curtailed or partially defeased mortgages. Moreover, it may be interesting to examine differential behaviours of early mortgage terminations for mortgages originated or observed in boom and bust periods. For parsimonious reasons, we haven't covered this analysis in our current empirical study but will conduct it shortly.

Besides, we will extend the current research field into relevant areas such as systemic risk in mortgage markets and interactions between labour and real estate markets. Regarding the systemic risk, we will examine the contagion risk of commercial mortgages to disentangle the determinants of commercial mortgage terminations from the impact of fundamental factors of collateral properties on the termination of commercial mortgages (e.g. collateral underlying property supply constrained markets, credit tenant lease and lease tenure). We could potentially offer insight on how to manage contagion risk if a contagion effect of commercial mortgage terminations exists. Finally, as far as interactions between labour and real estate markets are concerned, we intend to study the impact of the resonance driven by labour market shocks and real estate market shocks on both markets equilibria.

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