Catastrophic Risk and Credit Markets

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ABSTRACT

We provide a model of the effects of catastrophic risk on real estate financing and prices and demonstrate that insurance market imperfections can restrict the supply of credit for catastrophe-susceptible properties. Using unique micro-level data, we find that earthquake risk decreased commercial real estate bank loan provision by 22 percent in California properties in the 1990's. The effects are more severe in African-American neighborhoods. We show that the 1994 Northridge earthquake had only a short-term disruptive effect. Our basic findings are confirmed for hurricane risk, and our model and empirical work have implications for terrorism and political perils.

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Catastrophic events can dramatically affect the well-being of people throughout entire regions. Episodes such as September 11, 2001, the December 26, 2004 tsunami in Asia, and Hurricane Katrina in August 2005 highlight the risks borne by individuals, particularly those with limited financial resources. Financial markets can help to manage these risks by playing two crucial roles. First, markets provide a mechanism through which risk is allocated efficiently. Second, financial markets can serve as a stable source of funding during post-catastrophe periods. Little is known, however, about how well financial markets perform these functions. In this paper, we provide a model of the effects of catastrophe risk on the financing and pricing of properties and find corroborating evidence for the model using unique micro-level data on earthquake risk (the average annual loss due to earthquake damage) and credit.

We show that apparent inefficiencies in the supply of catastrophe insurance have a substantial ongoing distortionary effect on bank credit markets. In particular, our results indicate that earthquake risk reduced the provision of bank financing by approximately 12 percentage points (22 percent) in California commercial real estate loan markets in the 1990's. We also find, however, that the large 1994 Northridge earthquake affected the market for only about three months following the event. These results suggest that while catastrophic risk may not be generally allocated efficiently, the additional distortions caused by even significant catastrophic events are quite short-lived. Our work highlights general features of catastrophic risk markets that are shared by a variety of perils including hurricane, terrorism, and political risks. We extend our basic findings to hurricane risk and argue that our results imply that, in the absence of well-functioning insurance markets, terrorism risk is likely to discourage bank financing of properties in high profile U.S. cities and political risk may impede the development of corporate debt markets in emerging economies.

Our model examines the potential distortionary effect of catastrophe risk on credit markets.[1] We emphasize that bank financing of catastrophe-susceptible properties is likely to be inefficient. Banks do not specialize in monitoring whether property owners are implementing all positive NPV safety-enhancing investments. In the presence of a bank loan, due to a risk-shifting motive, owners may prefer not to make these investments. Insurers, by contrast, are expert in monitoring the execution of safety-increasing improvements, so the presence of a well-functioning insurance market can ameliorate the problems in bank financing of properties at risk of a catastrophe. Insurance

[1] The management of catastrophic risk has been the theme of a recent stream of research analyzing insurance (Jaffee and Russell, 1997, Niehaus, 2002, Zanjani, 2002), reinsurance (Froot and O'Connell, 1997, Froot, 2001) and catastrophic-loss derivatives (Cummins, Lalonde and Phillips, 2004).

markets, however, may be imperfectly competitive due to capital constraints (Winter, 1994 and Gron, 1994) or information asymmetries (Cummins and Danzon, 1997). Froot (2001) contends that catastrophe insurance, in particular, is over-priced and in relatively short supply due to capital market imperfections and market power enjoyed by the relatively small number of catastrophe reinsurers. We show that a poorly functioning catastrophe insurance market will lead to less bank financing of catastrophe-susceptible properties, reduced market participation by less-wealthy investors and incomplete insurance coverage. Inefficiencies in the catastrophe insurance market will also derail positive NPV investments by investors who require loans.

To test the theory, we perform an empirical analysis using unique data on catastrophic earthquake risk and commercial property loan contracts and prices in the U.S. in the 1990s. Using data from Standard and Poor's (S&P) ratings of commercial mortgage-backed securities (CMBS), we first show that only 35% of properties in earthquake zones carry earthquake insurance and the probability that insurance is purchased is increasing in earthquake risk. These findings are consistent with our model and suggest that earthquake insurance is inefficiently supplied.

To analyze the impact of earthquake risk on the provision of finance, we match property-level financing and price information on commercial property transactions from *COMPS*.com with a unique data set of micro-level earthquake risks, provided by AIR Worldwide Corporation (AIR). We find that increased earthquake risk dramatically reduces the likelihood that a property will be financed with bank debt, controlling for census tract fixed effects. Within-neighborhood identification is empirically feasible because differences in soil conditions create highly localized variation in the effects of earthquakes; the AIR earthquake risks reflect both fault location and detailed soil condition data. Our results suggest that in Los Angeles county, for example, the median quake risk reduces the probability of bank financing by over 20 percent, indicating that imperfections in the allocation of catastrophe risk can disrupt bank credit markets in a manner consistent with the theory.

We then examine the cross-section of properties to determine if these effects are stronger for different groups of buyers or properties in ways predicted by the theory. We show that when insurance firms (insurers or insurance brokers) purchase properties, earthquake risk has a significantly smaller affect on the probability that a bank loan is used to finance the property than it does for other buyers. Since insurance firms have better access to earthquake insurance, they are not as severely affected by the general lack of supply. As predicted by the model, the use of bank credit by insurance firms is thus less distorted by the presence of earthquake risk. We also find that properties in areas with large African-American populations are especially unlikely to be financed with bank debt in the presence of quake risk, controlling for the overall provision of bank loans. Earthquake insurance may be particularly hard to obtain in African-American neighborhoods for a variety of reasons, which would create more serious credit distortions linked to earthquake risk in these areas.

If there is a limited supply of earthquake insurance, intermediaries such as property brokers who repeatedly participate in the market may be able to cultivate cooperative relationships with insurance firms and facilitate their clients' access to insurance and hence bank loans. Consistent with this idea, we show that deals involving property brokers are especially more likely to receive bank financing in high-quake-risk areas. This result continues to hold when we instrument for property broker presence using the local thickness of the market for a particular property (brokers are used less often for properties that are traded in thick markets). Our final cross-sectional result is that quake risk reduces the probability of bank financing particularly for older buildings. Earthquakes may cause greater damage to older properties, so quake risk is probably more important for these buildings.

While we find strong evidence linking quake risk to bank loan provision, we show that the probability of seller financing is not strongly tied to quake risk. Although sellers face the same risk-shifting problem as banks, sellers, unlike banks, have excellent information about the property and are thus capable of ensuring that the safety-improving investments are undertaken. To further corroborate this story we show that when the seller's information is less relevant (e.g., for properties slated for development where the property is going to change dramatically) or less extensive (e.g., sellers with very short tenure in the property), the risk-shifting issue dominates and we get the same results linking quake risk to loan provision for these sellers as we do for banks.

Earthquake risk also influences the characteristics of buyers and financing banks. We find that in the pool of non-corporate buyers, the purchasers of high quake risk properties come from zip codes with higher median home values. This evidence supports the implication of the model that properties with higher catastrophic risks will be purchased by buyers who are wealthier on average. We also show that local banks are relatively more likely to finance high quake risk properties, which is consistent with the underlying premise of the theory that monitoring (better performed by nearby banks) is more important for properties with greater catastrophe risk.

In addition to its disruptive influence on real estate financing, our model shows that catastrophic risk has a direct effect on asset pricing: properties at risk for earthquake damage should have lower prices, reflecting their increased potential for physical destruction. We find, however, that it is only in larger deals that buyers consistently apply greater discounts to properties with higher quake risk than others in the same census tract. It may be that the indirect financing effects we model are most important for larger transactions.

We also examine the aftermath of one of the largest earthquakes in recent history, the January, 1994, Northridge earthquake, which caused an estimated \$42 billion in damages (\$14 billion of which was insured). The Northridge quake caused a negative shock to the supply of earthquake insurance, and we study the impact and longevity of this shock. Our analysis shows that, consistent with the theory, properties with high quake risk were especially unlikely to be financed with bank loans in the period directly following the Northridge quake. The insurance supply shock generated by the quake further exacerbated the reduced provision of bank loans to high catastrophe risk properties. The duration of this effect was approximately 3 months. We demonstrate that local banks were less likely to make loans to high-quake-risk properties in the period after the event. We also find that, as the model predicts, bank-financed transactions were concentrated in lower-risk properties following the Northridge quake, while cash-financed transaction displayed no such shift. The effects from the earthquake were short-term and had no significant long-term impact on the pricing or financing of catastrophe risk.

Our model emphasizes general features of catastrophic risk markets: lack of bank specialization in monitoring safety-improving investments and restricted supply of catastrophe insurance. These features are shared by an assortment of catastrophic perils including earthquake, hurricane, terrorism and political risks. Earthquake data is particularly suitable for testing the theory for two reasons. First, risk assessors can generate objective quantitative measures of earthquake risk. Second, earthquake risk varies at the highly local level, which enables the use of census tract fixed effects to control for unobservables.

To explore the broader implications of our findings, we extend the empirical work to an analysis of hurricane risk, which shares many of the features of earthquake peril. While the properties in our sample have relatively low exposure to hurricanes, we do find evidence that properties with higher hurricane risk than others in the same zip code tend to receive less bank financing. This effect is magnified when the price of catastrophe insurance is high. These results provide further evidence for the theory using a second catastrophic risk setting.

We argue that the supply of terrorism risk insurance, which has recently become a subject of intense interest, is likely to be even more restricted than that of natural disaster insurance for three reasons. First, terrorism risk is particularly difficult to evaluate and this ambiguity can hamper the supply of insurance (Hogarth and Kunreuther, 1985). Second, terrorism is endogenous, so markets set up to allocate terrorism risk may be manipulated (Poteshman, 2006). Third, the damages from a catastrophic act of terrorism may be may greater than those caused by natural phenomena. Consequently, the effects we document for earthquake risk may be even more severe for terrorism risk. A decision by the government to decline to support the terrorism insurance market (for example, by refusing to renew the Terrorism Risk Insurance Act) may have important consequences. Our work suggests that in the absence of government-subsidized terrorism insurance, high profile and high density areas such as the downtowns of large U.S. cities would likely experience both a significant shift away from bank financing of properties and market exit by less well-capitalized investors. Also, reconstruction after a terrorism incident would likely be hampered by limited supply of bank credit in the immediate period following an event.

Political risk such as nationalization or currency controls, which are typically of greatest concern in emerging economies, also exhibit properties similar to those of other catastrophic perils: huge potential losses and lack of bank skill in monitoring and liquidating affected investments. Political risk, like terrorism, also faces the problem of uncertain hazard assessment, and the supply of political risk insurance is quite limited (Hamdani et al., 2005). Our findings indicate that less well-capitalized firms that require financing will be significantly more likely to invest in emerging markets if there is a sufficient supply of fairly priced political risk insurance, and by extension will encourage the issuance of emerging market corporate bonds.

The remainder of the paper is organized as follows. Section I describes our theoretical model of the pricing and financing of catastrophe risk. Section II details the commercial real estate and earthquake data. Section III investigates the effects of earthquake risk on real estate financing and prices. Section IV analyzes the impact of the Northridge quake. In Section V we consider the implications of our findings for hurricane, terrorism, and political risks. Section VI concludes.

I. Model

We develop a theory of the pricing and financing of properties in the presence of catastrophic risk. We begin with a simple model of identical investors all of whom are financially unconstrained. We then consider the presence of an investor with a higher valuation (or private benefits), who is potentially financially constrained. We will argue that banks are inefficient at financing catastrophe-susceptible properties, but that this inefficiency can be ameliorated by insurers. We conclude the model by examining the implications of imperfections in the supply of catastrophic risk insurance for the financing of properties.

A. Unconstrained investors

For simplicity, consider a property generating cash flow C_t each period t with an associated discount rate r for these cash flows. We assume that $C_{t+1} = \alpha_{t+1} C_t$, where the $\{\alpha_s\}$ are mutually independent and $E[\alpha_s] = 1$ for all s. This implies that $E[C_{t+1}|C_t] = C_t$. Properties differ in their susceptibility to catastrophic (e.g., earthquake or hurricane) damage.[2] For each property, a parameter p describes both the probability that the property will be affected by a catastrophe and the severity of any such catastrophe. Each period t with probability p there is no catastrophe. With probability $1 - p$ a catastrophe occurs and leaves the property with a salvage value that is a fraction R_t of the undamaged property value V_t, where $R_t \in [0, 1]$ is a random variable.[3] We also assume for simplicity that the current cash flows are lost, though the results hold for fractional cash flow losses as well. We presume that the $\{R_t\}$ are identically and independently distributed, with common mean $E[R] \in [0, 1)$. We refer to $(1 - p)$ as the catastrophic risk of the property.

In the event of a catastrophe, we assume that instantaneous repairs costing $(1 - R_t)V_t$ must be undertaken before the property will generate future cash flows.[4] The net present value of these repairs when there is a catastrophe is $N(V_t, R_t) = V_t R_t \geq 0$. We assume that catastrophe risk (both frequency and severity) is uncorrelated with economy-wide financial wealth (as argued by

[2]The model applies to all cases of damage risk (e.g., fire), but, as we will discuss, the insurance supply distortions that play a role in the theory are most plausible for catastrophe risk.

[3]The scientific literature on earthquakes has established the Gutenberg-Richter frequency magnitude law, which states that magnitudes are governed by an exponential distribution, with relatively little variation across locations in the exponential parameter (Kagan, 1997). While the frequency of earthquakes can vary substantially across regions, the distribution of earthquake severities, given an event, is actually quite stable across areas. This result suggests that modelling the severity of the damage as independent of its frequency is reasonable. Hurricanes, cyclones and floods also exhibit similar frequency-magnitude patterns (MacDonald, 2000).

[4]Assuming that a catastrophe also changes the future cash flows generated by a property has no effect on the results.

Froot, 2001) and that investors are well diversified and financially unconstrained. Investors will always undertake the repairs, since $N \geq 0$.

The average annual loss q is defined as $q = (1-p)(1-E[R])$, which is the expected fraction of property value that is destroyed by the catastrophe in each period. The average annual loss is sometimes described as the catastrophe premium (Rüttener, Liechti and Eugster, 1999). Using standard arguments, we show in the Appendix that $V_t = \frac{pC_t}{r+q}$. The cap rate (ratio of earnings to price) is thus given by $\frac{r+q}{p}$.

The above straightforward discrete time model yields the basic intuitions necessary for our tests. Duffie and Singleton (1999) provide a general theoretical treatment of the pricing of assets in the presence of exogenous value-destruction risk.

Our first result describes the pricing effects of catastrophe risk: properties subject to catastrophe risk sell for lower multiples of their current cash flows.

Result 1. *The derivative of the cap rate with respect to the average annual loss is at least one.*

The proofs of all Results are given in the Appendix.

B. Constrained Investors and Differential Valuations

We now introduce two modifications to the base model. First, for a given property with current value V_s in period s, with probability ζ there is an investor who can generate an additional value $b \geq 0$ from purchasing the property and managing it for the next period. This additional valuation might arise from a positive net present value investment known only to the investor or from a private benefit. For simplicity we will assume that b is a private benefit, though our results are not sensitive to that assumption. The realization of b is known to the investor.

Second, we assume that this investor has wealth $w_L < V_s$ with probability $l \in (0,1)$. With probability $(1-l)$, the investor has wealth $w_H > V_s$. That is, we introduce financially constrained investors who do not have enough cash to purchase the property. The investor with a private benefit pays only the market value V_s if he purchases the property, just as he would if the property were sold in a public auction.

B.1. Inefficiency of Bank Financing in the Absence of Insurance

We begin by assuming that no catastrophic insurance is available. Constrained investors will require a bank loan. Banks have unlimited capital, and we assume that the banking sector is competitive; our focus is on credit market distortions that are related to catastrophic risk, rather than general credit market distortions. We presume that the bank financing of catastrophe-susceptible properties is inefficient.

We model this inefficiency as arising from the fact that banks do not specialize in monitoring whether a property owner is implementing all positive net present value (NPV) damage-reducing safety investments. In the presence of bank debt, an owner may prefer to forgo these investments, since they reduce the risk of the property, thereby increasing the value of the bank loan and potentially decreasing the value of the owner's equity (Smith and Warner, 1979). The bank financing of catastrophe-susceptible properties will thus lead to inefficient underinvestment in positive NPV safety enhancement projects.

Consider a property with value V_s that may experience a catastrophe with probability $(1-p)$. The argument just given suggests that if an investor purchases the property with w in equity and a bank loan of $V_s - w \geq 0$, then the inefficiency associated with bank financing will result in value destruction, which we denote by $loss(w, V_s, p)$. We will assume that the value destruction satisfies two properties:

Property 1: $loss(w, V_s, p)$ is decreasing in p and w

Property 2: $loss(w, V_s, p) > 0$ if $V_s > w$ and $p < 1$, but $loss(w, V_s, p) = 0$ if $V_s = w$ or if $p = 1$.

The first property captures the idea that the expected efficiency losses generated by the bank's lack of information and inability to monitor damage prevention projects are more severe both when the catastrophe risk is high and when the equity provided by the investor is low. The second property specifies that if there is no catastrophe risk, or if the project is wholly equity financed, then there is no value destruction. The presence of some catastrophe risk combined with bank financing always leads to a measure of inefficiency, however small.

In the Appendix we provide a formal model of imperfect bank information about safety investments and the resultant risk-shifting by property owners. We show that this model yields the two properties detailed above. What is central to our paper, however, is simply the idea that bank financing of catastrophe-prone properties is inefficient. This inefficiency might also be generated by a different model in which banks do not specialize in the evaluation or remediation of catastrophic damage, which may lead to inefficient foreclosure and liquidation by banks of properties damaged in catastrophes.[5]

[5] We presented a formal model of this idea in a previous draft.

We define $\Pi_B(w, V_s, p)$ to be the net present value received by this investor if he invests $w \leq V_s$ in cash and borrows $V_s - w$ in order to purchase a property with catastrophe frequency $(1 - p)$. The value of the investor's equity claim is equal to the value V_s of the property minus the value of the bank's debt claim minus any value destroyed in inefficient liquidation. Credit markets are competitive, so the net present value of the investor's investment is therefore equal to his private benefit minus the value destroyed in inefficient liquidation. Since not investing is always an option, we have

$$\Pi_B(w, V_s, p) = max\{b - loss(w, V_s, p), 0\}.$$

B.2. Insurance Market

We now introduce the possibility of catastrophe insurance. We assume there are two potential insurers who offer full insurance contracts (covering all cash flow and property value losses), though our results are not sensitive to either of these assumptions. Insurers differ from banks in that they know which safety-enhancing investments are positive NPV, and insurers can therefore offer contracts that are contingent on the owner undertaking these investments. Since these investments are positive NPV, optimal insurance agreements will incentivize owners to make them, in exchange for lower premia. The provision of insurance thus removes the source of inefficiency associated with the bank financing of properties subject to catastrophe risk.[6]

We presume, however, that the catastrophe insurance market is potentially imperfectly competitive. Imperfections may arise from a number of sources. Winter (1994) and Gron (1994) show that a combination of correlated insured losses, restrictions on the default probabilities permitted for insurers, and costly external financing leads to a capacity-constrained and imperfectly competitive insurance industry. Cummins and Danzon (1997) argue that policyholder switching costs, generated by learning over time both by policyholders about insurers and vice versa, can deter entry by new insurers. Froot (2001) describes the role of market power and capital constraints in the reinsurance industry. The infrequency of catastrophic events may exacerbate information

[6]This shown formally in the Appendix. One might ask why banks do not acquire the information expertise of insurers. It may be the case that acquiring such expertise involves large fixed costs that can only be justified by engaging in a full business of underwriting policies. That is, a bank would have to use this expertise as widely as insurance companies do, not just for properties secured by the bank's loans. Why, then, do banks not simply merge with insurers? Until the passage of the Gramm-Leach-Bliley Act of 1999, just shortly after the close of our sample period, this was legally difficult. Even after the passage of this act, however, such mergers carry with them the usual costs (e.g., loss of focus, agency problems) associated with universal banking in general. DeLong (2001) provides some evidence that diversifying mergers by U.S. banks do not create value, but Cybo-Ottone and Murgia (2000) show that European bank-insurance mergers do generate positive announcement effects.

asymmetries between potential investors and insurers, because it is difficult for outsiders to assess, in the absence of a catastrophe, how careful an insurer is offering coverage. This difficulty may serve to particularly constrict the flow of capital to potential entrants in the catastrophic insurance market.

We assume that each insurer is able to make a bid on any given catastrophe insurance contract with probability $n \in [0, 1]$. Whether an insurer can bid is independent of what happens to his competitor. Each insurer who can bid proposes a price for full insurance, and the property owner may select the lower bid or choose not to purchase insurance. We describe the insurance market as perfectly competitive if $n = 1$ and imperfectly competitive otherwise. The fair value of insurance is the market value of the insurance payout.[7]

We describe the bid of an insurer by viewing it as a mark-up, mar, over the fair value of the insurance. If both insurers bid for the contract, the unique equilibrium is for each to set $mar = 0$. If only one insurer bids, he will choose mar to maximize his expected profits. Financially unconstrained investors will never pay a positive premium for insurance, since they need not finance with a loan and will therefore never suffer the inefficiencies of bank financing, so the insurer maximizes the profits he realizes from selling to constrained investors. Any bid $mar > w_L$ will be rejected, since the investor has insufficient resources to pay this amount. The bid is also rejected if it is less expensive for the investor to purchase the property without insurance: $mar > loss(w_L, V_s, p)$. Lastly, if $mar > b$, the investor will prefer to forego the property purchase rather than buying insurance.

Insurers do not know the realization of the private benefit b, but they know its associated cdf F_b and pdf f_b. We assume that F_b satisfies the MHR property. We denote by b^* the solution to the following maximization problem:

$$\max_{y \geq 0} \left[y \left(1 - F_b(y)\right)\right]. \tag{1}$$

The MHR property guarantees that b^* is unique. An insurer bidding alone will set $mar = min\{b^*, w_L, loss(w_L, V_s, p)\}$. As a property's catastrophic risk increases, Property 1 indicates that the option of financing with a bank loan becomes increasingly unattractive. As catastrophe risk increases, two things occur in an imperfectly competitive insurance market: A single insurer bidding will charge a higher mark-up and, if no insurer bids, the investor is less likely to proceed with the

[7] For simplicity, we ignore the costs associated with damage assessment and monitoring. Including these costs does not affect the results.

purchase. Both of these effects reduce the frequency of bank-financed transactions. If the insurance market is perfectly competitive, insurance is always supplied at zero mark-up.

Result 2. *If the insurance market is imperfectly (perfectly) competitive, the probability that a transaction is financed with bank debt is decreasing (independent) in the property's catastrophic risk.*

In an imperfectly competitive insurance market, expensive insurance premiums combined with the inefficiency of bank financing in the absence of insurance together discourage less wealthy investors from purchasing properties with high catastrophic risk. Even though the credit market itself is competitive, the insufficient supply of insurance leads to distortions in the financing of catastrophe-susceptible properties. Investors with substantial wealth purchase the properties without insurance or a loan.

Result 3. *If the insurance market is imperfectly (perfectly) competitive, the average wealth of the purchasing investor is increasing (independent) in the property's catastrophic risk.*

As catastrophic risk increases, Property 1 implies that fewer financially constrained investors will buy the property without insurance. In an imperfect insurance market, if insurance is offered, the mark-up demanded will increase with catastrophic risk, but in such a way that the investor will still prefer to buy insurance rather than purchasing the property without it. The net effect is that as catastrophic risk increases, more of the bank-financed transactions will carry insurance. In a perfect insurance market, insurance will always be purchased because it avoids the inefficiencies of bank financing.

Result 4. *If the insurance market is imperfectly competitive, the probability that a bank-financed transaction is accompanied with insurance is increasing in the property's catastrophic risk. If the insurance market is perfectly competitive, all bank-financed purchases of properties with positive catastrophic risk will be accompanied with insurance.*

As catastrophic risk increases, in an imperfect insurance market, two classes of investors elect not to purchase the property. First, constrained investors who receive no insurance bid and find the cost of financing the property without insurance too high. Second, constrained investors who receive one bid and find both the insurance bid and the cost of financing the property without insurance too high. Since it is economically efficient for the investor to always purchase the property, this suggests that there are social welfare costs arising from imperfections in the insurance market: Positive net present value projects will be abandoned.

Result 5. *If the insurance market is imperfectly (perfectly) competitive, the probability of a transaction is decreasing (independent) in the property's catastrophic risk.*

We also consider the effects of a change in the competitiveness of the insurance market, such as might arise following a large catastrophic event. As competitiveness decreases, financially constrained investors will be unable to purchase affordable insurance and will not be able to make bank-financed purchases.

Result 6. *The probability that a transaction is financed with bank debt is increasing in insurance market competitiveness* n*.*

An increase in competitiveness will particularly benefit constrained investors considering purchasing high-catastrophe-risk properties. Thus, as competitiveness increases, there should be an especially large increase in bank-financed purchases of high-risk properties. Unconstrained investors using cash to make their property purchases will be unaffected by the competitiveness of the insurance market.

Result 7. *The average catastrophic risk of bank-financed transactions is increasing in insurance market competitiveness* n*. The average catastrophic risk of all-cash transactions is independent of insurance market competitiveness* n*.*

In Section III we will test these predictions using empirical data on earthquakes. Clearly, in practice, the insurance market will not be perfectly competitive. Our empirical results, however, will examine the importance of this imperfection and quantify its spillover effects on credit markets.

B.3. Seller Financing

After bank loans, the second most common form of debt in commercial real estate markets is seller financing. Our model does not make unambiguous predictions about the relationship between seller financing and catastrophe risk. On the one hand, sellers have excellent information about the properties they are financing, since they previously owned them. Just as we assume that the new owner is aware of which safety-enhancing investments are positive NPV, it is reasonable to presume that the previous owner also knows which investments will create value. If that is the case, the sellers can condition their mortgage terms on these investments being made, precisely as we described for the insurers. Banks, on the other hand, lack this information, and cannot enforce contract terms of this kind. Seller financing would therefore not lead to inefficient underinvestment in the presence of catastrophe risk, since the terms of the seller financing would condition on appropriate maintenance and investment to protect the property. Hence, the property-specific knowledge of the seller can be used to avoid underinvestment in a manner analogous to the general safety investment knowledge of the insurer. Seller financing would not be affected by the presence of catastrophe risk (or it might increase, as it substitutes for bank debt).

The counter argument is that sellers may not be as expert as insurers at monitoring the implementation of safety investments, and hence the frequency of seller financing will be reduced by catastrophe risk, just as it would be for bank financing. Given the theoretical indeterminacy of this question, we leave the relationship between seller financing and catastrophe risk to be considered as an empirical issue.

II. Data and Summary Statistics

We briefly describe the variety of data sources used in the paper.

A. Transaction-level data from the U.S. commercial real estate market

Our transaction-level commercial real estate sample consists of 32,618 transactions drawn from across the U.S. over the period January 1, 1992 to March 30, 1999 compiled by *COMPS*.com, a leading provider of commercial real estate sales data. Garmaise and Moskowitz (2003, 2004) provide an extensive description of the *COMPS* database and detailed summary statistics. The data span 11 states: California, Nevada, Oregon, Massachusetts, Maryland, Virginia, Texas, Georgia, New York, Illinois, and Colorado, plus the District of Columbia.

Commercial properties are grouped into ten mutually exclusive types: retail, industrial, apartment, office, hotel, commercial land, residential land, industrial land, mobile home park and special. Panel A of Table I reports summary statistics on the properties in our sample. The average (median) sale price is $2.2 million ($590,000), and there are only 42 transactions involving REITS (less than 0.2% of the sample). Capitalization rates, defined as current net income on the property divided by sale price, and property age are also reported.

The *COMPS* database provides detailed information about specific property transactions, including property location, identity and location of market participants, and financial structure. In particular, *COMPS* provides eight digit latitude and longitude coordinates of the property's location (accurate to within 10 meters).

The *COMPS* data contain financing information for each property transaction. We focus on the terms of the loan contract, including interest rates, and the size and presence of loans. As Panel A of Table I indicates, the average loan size (from bank and non-bank institutions) as a fraction of sale price is over 75%. Bank loans are used in 53% of transactions, vendor-to-buyer (VTB) loans (i.e., seller financing) are used in 19% of deals and less than 5% of deals involve assumed debt. The data also contain rich detail on loan terms including the annual interest rate, the maturity of the loan, whether the loan rate is floating or fixed, whether amortized and the length of amortization, and whether the loan is subsidized by the Small Business Administration (only 1.3% of loans). The *COMPS* data do not, however, include insurance information on properties.

B. Commercial Mortgage-Backed Securities Data

We make use of data on CMBS transactions provided by the S&P RatingsDirect database. This data provides descriptive details on fifty CMBS transactions over the period 1996 to 1999. Each CMBS issuance covers multiple properties, as described in Panel B of Table I, and in many cases information on earthquake risk and insurance is given.

C. Earthquake risk

AIR Worldwide Corporation (AIR) provides detailed data on the earthquake risks associated with our *COMPS* properties' locations (accurate to within 10 meters). AIR is a highly regarded vendor of estimates for various types of catastrophe risks. Using its proprietary CATStation Hazard Module, AIR generates location-specific assessments of the expected average annual loss due to earthquake risk. (Cummins, Lalonde and Phillips, 2004 describe the AIR catastrophe models.) The average annual loss denotes the fraction of property value that is expected to be destroyed by an earthquake in any given year. It is expressed as a percentage, and it reflects both the likelihood of an earthquake and the distribution over potential severities. Property characteristics will also have an effect on the impact of an earthquake, but the AIR estimates incorporate *only location, not structure or characteristics*.[8] We use AIR's estimate of average annual loss as our measure of quake risk.

The AIR earthquake model uses both fault location and detailed soil condition data. Soil characteristics have a large impact on the way seismic waves are transmitted. Using this data, the AIR model makes highly localized predictions of average annual loss. For example, the AIR soil database for the area around the San Francisco Bay has a horizontal resolution of 24 square meters.[9]

[8] AIR does generate structure-specific estimates, but these were not provided to us.

[9] This description of the AIR model is drawn from http://www.air-worldwide.com. The January 1994 Northridge earthquake caused some revisions to earthquake risk assessments. All the results in the paper are robust to using

Panel B of Table I presents summary statistics for AIR earthquake risks. For most properties in our sample, the average annual loss is described as less than 0.1%, which we code as 0. There are 9,785 properties with positive quake risks, all located in California, Oregon and a handful of sites in Massachusetts. Our data include 12,288 properties in California and 9,386 properties in Los Angeles county.

In many cases the S&P data supplies earthquake risk and insurance data on the properties securing the CMBS issuance. For properties in earthquake zones (primarily California, but also including parts of Nevada, Washington, Oregon, Utah and Missouri) the probable maximum loss (PML) is often specified, along with information about whether the property has earthquake insurance. S&P defines the PML to be the expected earthquake damage (expressed as a fraction of property replacement cost) that has a ten percent chance of being exceeded during a fifty year period (Standard and Poor's, 2003). This measure of earthquake risk is closely related to the average annual loss. In most cases, the S&P data will specify only whether the PML exceeds a threshold, typically 20%.

D. The Northridge Earthquake

Our data and sample period also allow us to consider the impact of an actual sizable earthquake, the Northridge earthquake of January 17, 1994. The Northridge earthquake measured 6.7 on the Richter scale, caused 57 deaths and was responsible for direct economic damages of approximately $42 billion (of which $14 billion was insured), according to reliable estimates (Petak and Elahi, 2000). The U.S. Geological Survey (USGS) provides data on the severity of ground motion during the Northridge quake.[10] Specifically, we consider the peak ground acceleration (PGA), which is the maximum acceleration experienced at a specified location on the earth's surface during the course of an earthquake. The PGA is a commonly used metric for earthquake severity, and building codes often describe requirements for withstanding shaking in terms of horizontal force, which is related to PGA. Data is provided for points on a grid system, with a distance between grid points of approximately 1.15 miles on the north-south axis and 0.94 miles on the east-west axis. We match our property locations to the nearest grid point in order to infer the extent of local PGA. This process generates PGA estimates for every *COMPS* property in Los Angeles county. Summary statistics are given in Panel B of Table I.

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only post-January 1994 data.

[10]The data may be found at http://earthquake.usgs.gov/shakemap.

E. Crime and Census Data

We also make use of local crime and census data. The crime risk data is provided by CAP Index, Inc., and vary within census tracts (see Garmaise and Moskowitz (2005) for further details). The census data come from the 1990 and 2000 U.S. censuses.

III. The Effects of Earthquake Risk on Financing and Prices

Using the earthquake risk and commercial property loan data, we test the hypotheses outlined in Section I by examining the impact of earthquake risk on financing and prices. We also provide some general descriptive statistics on the effects of earthquake risk on commercial real estate markets. The commercial real estate market is a useful laboratory to investigate the role of catastrophe risks because the loans are typically secured and non-recourse, providing a set of project-specific financings for which the collateral value is of central importance.

A. Quake risk and insurance

The theory in Section I advanced the argument that an imperfectly competitive catastrophe insurance market can impede the supply of credit in the real estate market. Catastrophe insurance reduces the costs of securing a loan because it encourages owners to make all safety-enhancing positive NPV investments. If catastrophe insurance is priced at a premium, as suggested by Froot (2001), then buyers who require a loan will only purchase insurance when the costs of inefficient bank financing are very high, i.e. for high-quake-risk properties. This idea is captured in Result 4, which states that in imperfectly competitive insurance markets the probability that a bank-financed transaction is accompanied with insurance is increasing in the property's catastrophe risk. In perfectly competitive insurance markets, all bank-financed properties should carry insurance.

Insurance data on individual properties is quite difficult to secure (Squires, O'Connor and Silver, 2001), but the S&P CMBS database provides this information on properties in quake-susceptible areas as part of its ratings process. The properties in this database have securitized loans, which make up a significant (and growing) fraction of total commercial mortgage lending during our sample period.[11] Hence, these properties are representative of our larger database on commercial real estate from *COMPS*, which does not contain information on quake insurance. Panel C of Table I shows that for the 482 properties in the S&P CMBS transactions that reside in quake-prone areas,

[11] Vandell (1998) shows that by the end of 1997, 15.1 percent of general commercial real estate mortgage credit was securitized, while 25.5 percent of apartment debt was securitized.

only 169 or 35% purchased earthquake insurance. Among properties facing the highest quake risk (those with probable maximum loss, PML, > 20%), the fraction obtaining earthquake insurance is 54%. These results are consistent with Result 4 from the model of Section I.

As a more formal test, Table II presents results from regressions relating quake risk to the purchase of quake insurance in the S&P CMBS database. We regress a binary variable for whether quake insurance was purchased on an indicator variable for High quake risk (PML above 20%). Unfortunately, the S&P CMBS database does not provide information on quake risk other than identifying properties as high or low quake risk based on having a PML greater than 20%. All regressions include year dummies and transaction attributes and robust standard errors are reported throughout. In the first column of Table II, we display results from a logit regression. The coefficient on High quake risk is highly statistically significant (t-statistic of 7.41). In the second column of Table II, we describe the results of a fixed effects (conditional) logit regression that includes CMBS issuer fixed effects. The coefficient on High quake risk remains statistically significant and its point estimate is largely unchanged. The economic magnitude of this effect is quite large. The point estimate on High quake risk in the conditional logit specification implies a 33.80 percentage point increase from 35.06% to 68.86% in the probability of earthquake insurance being provided.[12] For this sample of debt-financed earthquake-zone properties, those with a PML of at least 20% (e.g., high quake risk) have a dramatically higher probability of carrying earthquake insurance than other properties. The third column of Table II uses transaction-level rather than issuer-level fixed effects. The magnitude of the coefficient on high quake risk diminishes somewhat, but remains significant in both statistical (t-statistic = 3.04) and economic terms (24.4 percentage point increase).

The findings in Table II are consistent with other work showing that lenders require earthquake insurance for high risk properties (Glickman and Stein, 2005) and that commercial real estate investors purchase earthquake insurance primarily at the request of lenders (Porter et al., 2004). Overall, the results are consistent with the imperfect-insurance equilibrium of Result 4. Result 4 indicates that in an imperfectly competitive insurance market not all loan-financed properties will carry insurance, and the fraction with insurance will rise with quake risk. The evidence in Table II and the fact that only 35% of the properties in quake zones carry insurance strongly supports the

[12]The economic magnitude of a fixed effects logit is best considered in terms of its impact on the odds ratio. Earthquake insurance is provided for 35.06% of the CMBS earthquake-zone properties, which gives an odds ratio of $\frac{0.3506}{1-0.3506} = 0.5399$. Since the estimated coefficient on High quake risk is 1.41, moving from low to high quake risk multiplies the odds ratio by $exp(1.41) = 4.10$, which yields an odds ratio of 2.21, which is equivalent to an earthquake insurance probability of 68.86%.

model. The fact that these loans are securitized in public markets makes clear that diversification of catastrophe risk is not the primary role played by insurance in the financing of properties. The purchasers of public CMBS are very well diversified and cannot credibly be argued to be over-exposed to earthquake risk. The model presented in Section I, however, shows that even properties financed by well-diversified lenders will carry earthquake insurance, so that lenders (and, indirectly, borrowers) can avoid inefficient liquidation.

B. Quake risk and commercial financing terms

Table II provides evidence of an imperfectly competitive catastrophe insurance market. According to Result 2, in an imperfectly competitive insurance market the probability of bank financing will decline with catastrophic risk, while in a perfect insurance market bank financing and catastrophic risk will be unrelated. As an additional test of the competitiveness of earthquake insurance markets, we examine the relation between bank financing and earthquake risk. Table III considers the effect of quake risk on the commercial real estate financing terms offered by banks. To isolate the impact of quake risk, it is important to control for neighborhood features, since the lending environment can vary across different districts of a city (Ross and Tootell (2004), Garmaise and Moskowitz (2005)). We conduct our tests using census tract fixed effects to difference out unobservables at the census tract level. A census tract typically covers between 2,500 and 8,000 persons or about a 4-8 square block area in most cities, and is designed to be homogeneous with respect to population characteristics, economic status, and living conditions (source: United States Census Bureau). Quake risk, however, is not uniform within a census tract due to highly localized variation in soil conditions. There are 1,210 tracts in our data set that contain properties with positive quake risks, and 202 tracts (with 2,235 properties) that have within-tract variation in quake risk. While earthquake risk is clearly highly variable across different regions of California and the U.S., we emphasize that we are only comparing properties within the same tract and our econometric identification arises solely from within-tract variation.

More formally, our econometric model considers the effect of earthquake risk on the provision of loans by banks, a binary variable indicating whether a bank loan was obtained. The equation estimated is,

$$Prob(bank\ financing)_i = F(quake\ risk_i, price_i, controls_i, property\ type, year, tract) + \epsilon_i, \qquad (2)$$

where $controls_i$ is a vector of controls containing a set of property and neighborhood attributes for asset i, *property type*, *year*, and *tract* represent property type, year, and census tract fixed effects, and ϵ_i is an error term. The sale price is included as a regressor to control for value in current use, thereby isolating the component of quake risk related to secondary or collateral value, since the theory we aim to test is about liquidation value in the event of a catastrophic risk. We estimate a logistic functional form for the binary dependent variable.

In advance of our discussion of the empirical results, it is worthwhile to consider the econometric issues raised by our specification in equation (2). The first point is that the sale price itself may be a function of quake risk; we might expect high quake risk properties to realize lower prices according to Result 1. We examine the evidence testing this result in the next section. This issue presents no special econometric problem because the logistic model can be estimated consistently in the presence of correlations between independent variables.

The second, and more serious, issue is that some unobservable variable, such as local financial and economic conditions or quality of borrower or property, may have a simultaneous effect on loan provision, sale prices, and quake risk, rendering all of our variables endogenous and difficult to interpret. We address this issue by using census tract fixed effects to difference out unobservable at a level much finer than local financial markets operate and by controlling for the current sale price of the property, which should capture unobservables affecting market value and quake risk simultaneously. In addition, because the commercial real estate loans we study are non-recourse, only variables affecting collateral value should matter, and hence quality of borrower or other attributes are less relevant. We provide a more detailed discussion of the omitted variables problem and how we deal with it in the Appendix.

We are essentially estimating reduced form equations for the probability, price, quantity, and terms of the debt supplied. Consistent with the model in Section I and as Benmelech, Garmaise, and Moskowitz (2005) argue and show, because of their non-recourse feature, commercial real estate loans are much more likely to reflect the borrower's debt capacity, and hence the effects we are measuring are closer to supply-side constraints.

B.1. Bank loan provision

In column 1 of Table III, we report results from regressing a binary variable indicating whether or not the property purchase is financed with a bank loan on quake risk – the average annual loss from the AIR data – and a set of control variables. The control variables include a set of property, borrower, and local market characteristics which include the log of the sale price, an indicator for whether the transaction is brokered,[13] an indicator for whether the buyer is a broker himself, an indicator for corporate buyers, the 1990 property and personal crime risks, the age of the property, the distances of the buyer and seller from the property, an indicator for development projects, and fixed effects for property type, year, and census tract. The estimation method is via fixed effects (conditional) logit. The regression shows that properties subject to greater quake risk are significantly less likely to be financed with a bank loan. The coefficient on quake risk is -2.63 with a t-statistic of -2.83. To evaluate the economic magnitude of this effect, consider the Los Angeles county observed frequency of financing of 58.5% and median quake risk of 0.2%. The point estimate on quake risk in the regression implies a 13.1 percentage point reduction in the probability of bank loan provision from 58.5 to 45.4%.[14] This reduction is 22.3% of the mean bank financing frequency. (The mean quake risk in Los Angeles county is 0.25%, which generates an even larger effect.) Examining all the California properties in our data set, for which the mean quake risk is 0.19%, the conditional logit estimate implies a 12.4 percentage point reduction in the probability of bank financing, which is 22.2% of the mean. The size of these effects suggests that quake risk dramatically reduces the provision of bank finance to properties at higher risk *within* the same census tract (and controlling for price and all the other attributes).

The substantial reduction in loan provision for high quake risk properties lends support to Result 2 from our model: in a well-functioning insurance market there should be no relation between earthquake risk and loan provision. If catastrophe risk is not efficiently supplied, then credit markets may be distorted. This evidence corroborates Froot's (2001) contention that catastrophe, in particular earthquake, risk is not optimally allocated across market participants and may not be correctly priced. Moreover, the magnitude of the effect we document suggests insurance markets can have substantial distortionary effects on credit markets. A 22% reduction in the frequency of bank financing can have significant effects on the real economy, as the finance and growth literature emphasizes ((Peek and Rosengren (2000), Cetorelli and Gambera (2001), Klein, Peek, and Rosengren (2002), Burgess and Pande (2003) and Garmaise and Moskowitz (2005)). As emphasized in the model in Section I (Result 5), financially constrained investors are forced to forego positive NPV projects when they cannot purchase fairly priced insurance.

[13] Garmaise and Moskowitz (2003) show that brokers have a significant effect on the financing of commercial properties through their relationships with banks. We therefore add broker presence as an additional control.

[14] The economic magnitude is calculated using the odds ratio, as described earlier. If, instead of a conditional logit model, we run a fixed effect linear probability model (OLS), the estimated effect of a 0.2% increase in quake risk is -9.2 percentage points, with a t-statistic of -2.51 (not reported in the tables).

B.2. Bank loan terms

In columns 2 and 3 of Table III we analyze the effect of quake risk on the terms of the bank loan contract. Our theory does not provide clear predictions about these terms but we provide some empirical evidence to offer additional descriptive information. We first consider interest rates. In our theory, some constrained investors purchasing quake-susceptible properties obtain a mortgage and acquire quake insurance. For these loans, there is no quake risk faced by the borrower and the loans are secured by both the property and the quake insurance. For a given ratio of loan amount to property value, these loans are actually safer than loans to properties with no quake risk (because of the value of the insurance) and may therefore carry lower interest rates. Other constrained buyers purchasing properties subject to quake risk obtain a mortgage without quake insurance. These loans will be riskier than loans secured by properties without quake risk and will therefore carry higher rates. The overall effect is ambiguous.

Column 2 reports regression results of the interest rate of the loan on quake risk. In addition to the previous controls, the ratio of loan size to property price (loan-to-value), the debt maturity, an indicator for floating rate loans, an indicator for Small Business Administration-backed (SBA) loans, and the log of bank assets are included as regressors. We find that quake risk has no statistically or economically significant effect on the interest rate. A 0.2% increase in quake risk is associated with a 17 basis point increase in the annualized interest rate, but the 95% confidence interval extends from -35 basis points to $+69$ basis points.

We next consider leverage ratios. The relationship between leverage ratios and quake risk is also ambiguous in the model because any feasible loan amount is optimal when insurance is acquired. Nonetheless, to fully describe the effect of catastrophe risk on financing terms, we regress bank loan size on quake risk. As is shown in column 3 of Table III, conditional on a loan being extended, the size of the loan does not depend on quake risk. In unreported results, we also find that other attributes of the loan, such as maturity, floating/fixed rate status and the presence of multiple lenders are also not affected by quake risk. The central feature of the relationship between quake risk and financing is the one highlighted in column 1: high quake risk properties are significantly less likely to be financed with bank debt, consistent with Result 2 when insurance markets are not fully competitive. Moreover, the lack of a relationship between quake risk and loan terms suggests omitted variable bias is not likely an issue since borrower selection or matching to properties should affect loan terms as well as loan provision. We elaborate on this point in the Appendix.

B.3. Seller Financing

In Section I B.3. we argued that the model does not make unambiguous predictions about the effects of catastrophe risk on the provision of seller financing. Sellers are very knowledgeable about their properties, so they can condition their financing on the implementation of specific damage-reducing investments, in a manner that banks cannot. Just as for insurers, these contractual provisions will appropriately incentivize the owner to make positive NPV investments. Sellers, however, may not be as skilled as insurers at monitoring owners. We left the relationship between catastrophe risk and seller financing as an empirical question, which we take up in this subsection.

In column 4 of Table III we report results from regressing a binary variable for the presence of seller financing on quake risk, the usual controls and four additional seller controls: the log of the median home value in the seller's zip code (a proxy for seller wealth) and indicators for sellers that are located out of town, sellers that are corporations and sellers that are banks. We only include data for which these variables are available. In this regression, we find an insignificant effect of quake risk on the provision of seller financing. This result is consistent with sellers knowing which damage-reducing investments should be made and insisting upon them as part of the loan agreement.

To further investigate this point, we repeat the regression described in column 4, adding as an additional regressor the interaction between quake risk and an indicator for whether the property is slated for development. Presumably, the seller's knowledge of the property and the necessary safety investments is less relevant when the property will be substantially changed in the course of development. In untabulated results, we find that the coefficient on quake risk is 0.57 (t-statistic=0.50), the coefficient on the quake risk-development interaction term is -3.44 (t-statistic= -3.97) and the coefficient on development is 0.002 (t-statistic = 2.68). The negative and significant coefficient on the interaction is evidence that for development projects, quake risk does lead to less provision of seller financing, consistent with the seller's information being less material for these properties.

We undertake an additional analysis of seller financing for the 865 transactions that are sales of properties that have earlier recorded sales in the data. For this sub-sample, we can construct a measure of seller tenure in the property. Presumably, sellers learn about their properties over time, so seller information should be correlated with seller tenure. For this sub-sample, we repeat the regression described in column 4, including as additional regressors the log of seller tenure and the interaction between the log of seller tenure and quake risk. Due to the small sub-sample size, this model is not identified with census tract fixed effects, so we estimate it with zip code fixed effects. In untabulated results, we find that the coefficient on quake risk is -49.44 (t-statistic=-2.64), the coefficient on the quake risk-log(seller tenure) interaction is 2.49 (t-statistic = 1.76) and the coefficient on log(seller tenure) is -0.29 (t-statistic = -1.40). The negative and significant coefficient on quake risk suggests that for sellers with very short tenures, quake risk reduces the provision of seller financing, as it does for bank debt. The positive and significant coefficient on the interaction indicates that the impact of quake risk on the provision of seller financing decreases with seller tenure. Taken together, these findings support the argument that it is the seller's information about the property that mitigates the impact of quake risk on seller financing. Seller financing is thus different from bank financing, because banks lack the seller's specialized knowledge of the property. In light of these results, the remainder of the paper focuses on bank debt; bank loans are a central source of financing and it is the interaction between the bank's lack of knowledge and inability to monitor the property and potential imperfections in the supply of catastrophe insurance that is at the heart of the model.[15]

C. Cross-sectional Effects of Quake Risk on Bank Financing Terms

We further examine the role of quake risk on bank financing across various property attributes as a further test of our model and to help rule out alternative explanations. We first consider the purchase of properties by insurance firms (either insurers or insurance brokers). There are 102 insurance firms in our full sample. These insurance firms are likely to have strong relationships with catastrophe insurance providers (perhaps within their own company) that should facilitate their access to insurance. In essence, more catastrophe insurers are likely to bid on a property purchased by an insurance firm, so the insurance market faced by insurance firms will be more competitive. Result 2 indicates that catastrophe risk will have a smaller effect on the likelihood that an insurance firm purchases a property with a bank loan, relative to other buyers.

C.1. Insurance Firms

In the first column of Table IV, we describe the results from regressing an indicator for the provision of a bank loan on quake risk, quake risk interacted with an indicator for an insurance firm buyer,

[15] Aggregating bank and seller financing yields results that are broadly consistent with those for bank financing alone, though somewhat weaker.

an indicator for an insurance firm buyer and the usual controls. (The coefficients on the controls are not reported for brevity.) The coefficient on the interaction between quake risk and insurance firm buyer is positive and significant. As Ai and Norton (2003) discuss, however, the magnitude of the interaction effect in a logit model does not depend only on the estimated coefficient on the interaction term. To evaluate the magnitude of the interaction, we use the Ai and Norton (2003) methodology to calculate the effect on the probability of loan provision of an increase in quake risk from 0 to 0.2% for both a property purchased by an insurance firm and for a property purchased by a non-insurance firm, holding all other variables at their medians.[16] The magnitude of this interaction effect is 25.0 percentage points (with $t - stat = 2.31$), indicating that quake risk reduces the provision of bank financing to insurance firms by substantially less than it does for other borrowers. Considering both the direct effect of quake risk and the interaction effect of quake risk with the insurance firm buyer indicator, we find that quake risk has an insignificant effect on the probability that an insurance firm will finance a property with a bank loan, in contrast to its strong negative effect for other buyers. This evidence further supports Result 2.

C.2. African-American Neighborhoods

In the second column of Table IV, we examine the interaction of quake risk with the percentage of African-Americans in the property's census tract on bank loan provision. The regression includes the interaction between quake risk and the following tract-level variables as controls: the log of median home value, the log of median income, the unemployment rate, and the fraction of the local populace with a high school diploma. We find a negative and significant coefficient on the interaction term between quake risk and African-American percentage. Using the same methodology as described above, we calculate the effect on the probability of loan provision of an increase in quake risk from 0 to 0.2% for both a property located in a tract with the median plus one standard deviation percentage of African-Americans and for a property in a tract with the median percentage African-Americans. The magnitude of this interaction effect is -40.5 percentage points (with $t - stat = -3.74$), which shows that quake risk reduces the provision of bank loans especially in neighborhoods with more African-Americans. This finding is consistent with the idea that property insurance is particularly difficult to acquire in African-American neighborhoods, even controlling for local home values (Squires, 2003). The census tract fixed effects control for any reduction in

[16]Specifically, we subtract the latter change in probability from the former. We use the Ai and Norton (2003) method to analyze all logit interactions in the paper.

the general availability of bank credit in African-American neighborhoods, so this result suggests that distortions in the insurance market affect the supply of bank loans in these areas. An imperfect supply of catastrophe insurance thus serves to especially harm areas with greater minority populations. It may be that these neighborhoods have a higher concentration of properties that are priced below replacement costs (Glaeser and Gyourko, 2005). Such properties would likely not be suitable for insurance.[17]

C.3. Brokered Deals

The model suggests that a shortage of insurance may restrict bank financing of transactions. Property brokers, who participate repeatedly in this market, may be able to cultivate cooperative relationships with insurance suppliers that enable their clients to obtain insurance more easily. The results described in the first two columns of Table IV suggest that brokers facilitate their clients' access to bank financing in general, and brokers may be particularly effective in obtaining bank debt for difficult-to-finance high quake risk properties. To test this hypothesis, we regress bank loan provision on quake risk, an indicator for a brokered transaction, an interaction between quake risk and an indicator for a brokered transaction (plus the usual controls). As displayed in the third column of Table IV, the interaction term is positive and highly significant. Considering an increase in quake risk from 0 to 0.2% for both a property purchased in a brokered transaction and for a property purchased in a non-brokered transaction, we find an interaction with a magnitude of 4.6 percentage points ($t - stat = 2.56$). This suggests that broker intermediation leads to more bank financing particularly for high quake risk properties.

To investigate the concern that participants in brokered transactions may have unobserved qualities that drive their access to finance, but that are not related to the actual function of the property broker, we consider an instrumental variable approach. For each property we define the thickness of its market to be the fraction of the properties sold in its census tract that are of the same type (e.g., apartment, retail, commercial, etc.) minus the fraction of all properties sold in the full data set that are of its type. That is, the market thickness measures the relative frequency of sales of properties of the same type within the local area. Brokers are presumably needed more for facilitating the sale of properties that are relatively unusual in their neighborhoods. We first regress the indicator for brokered transactions on market thickness and the usual controls, and we denote

[17]Although the west coast cities in our data with significant quake risk have only a small fraction of properties with values below replacement cost, such properties are likely to be concentrated in disadvantaged areas. We thank an anonymous referee for this point.

the estimated probabilities from this regression by $\widehat{brokered}$. In this regression, market thickness enters with a negative and significant coefficient (t-statistic $= -4.60$), as expected. We then estimate the broker-quake risk interaction effect using 2SLS,[18] using $\widehat{brokered}$ and $(Quake\ Risk) * \widehat{brokered}$ to instrument for the brokered indicator and its interaction with quake risk. As shown in the fourth column of Table IV, the interaction term is positive and highly significant, providing clear evidence that broker intermediation promotes bank loan provision for high quake risk properties. Our use of an instrumented strategy suggests that this finding is not likely due to unobserved characteristics of brokered transactions.

C.4. Older Properties

The effect of the reduction in bank loan provision induced by earthquake risk is not uniform across properties. Due to innovations in technology, improved building codes and structural deterioration, older properties are likely more susceptible to earthquake damage than younger, seismically-modernized properties (Schulze et al., 1987 and Otani, 2000). Conversely, it may be argued that for older properties, the land is a larger proportion of total property value and land is presumably less subject to earthquake risk. Moreover, older buildings that have survived earlier earthquakes may be more robust. While our theory does not provide clear guidance on this question, we nonetheless explore the connections between building age, quake risk and bank loan provision. In the fifth column of Table IV, we report results from regressing an indicator for the provision of a bank loan on quake risk, quake risk interacted with property age, property age and the usual controls. The coefficient on the interaction between quake risk and age is highly significant and negative. Comparing an increase in quake risk from 0 to 0.2% for both a property of median plus one standard deviation age and for a property of median age, we find an interaction with a magnitude of -6.9 percentage points ($t - stat = -5.12$). This shows that quake risk has a stronger effect on the bank financing of older properties.

D. Earthquake risk and Selection of Buyers and Banks

Result 3 states that in an imperfectly competitive catastrophe insurance market, the average wealth of the purchasing investor is increasing in the catastrophe risk of the property.[19] The COMPS data

[18]We estimate a linear probability model due to the instrumenting strategy and the presence of census tract fixed effects.

[19]In the model, catastrophe risk determines the distribution of both the capital structure and buyer wealth for a given property. Capital structure and buyer wealth are thus jointly determined endogenous variables: properties with greater catastrophe risk are bought by wealthier buyers who can purchase them with less bank debt. In an

do not provide the wealth of property buyers, but they do list the zip code of the purchaser. (The census tract of the buyer is not given.) For non-corporate (i.e., individual) buyers, the median home value in the buyer's zip code (from the 2000 census zip code tabulation area data) is a reasonable proxy for the buyer's wealth. In column 1 of Table V, we display the results from regressing the median home value in the buyer's zip code on quake risk and the usual controls, in the subsample for which the buyers are non-corporate. We find a positive and significant coefficient on quake risk: within a given census tract, the buyers of higher quake risk properties tend to come from wealthier zip codes, consistent with Result 3.

In column 2 of Table V we regress the fraction of the issuing bank's deposits that are held within the same county as the property on quake risk. We only include observations that include a loan and for which we can identify the lending bank in this regression. We find a marginally significant *positive* coefficient on quake risk; local banks are *more* likely to make loans in high quake risk areas. It is reasonable to suggest that monitoring the implementation of safety-enhancing investments may more feasibly be done by a local bank. This finding supports the assumption of the model that monitoring (better performed by closer banks) is important in the financing of properties subject to catastrophic risk.

The finding in column 2 also suggests that the need for diversification is unlikely to serve as an explanation for the importance of quake risk to financing. In this case, the risk would best be borne by distant banks. As further evidence against this alternative, in column 3 of Table V we display results from regressing the log of bank assets on quake risk, the size of the loan, and the previous set of controls. As the table indicates, banks making loans in high quake risk areas are *not* significantly larger in terms of asset size. Larger banks could presumably more easily diversify their exposure to catastrophe risk. These results therefore do not provide support to a risk diversification motive.

E. Quake risk and commercial real estate pricing

Result 1 states that property cap rates should increase with quake risk, on at least a one-to-one basis. We test this hypothesis by regressing cap rates on quake risk and the full set of controls from Table III. We report the results from this regression in column 1 of Table VI. The results are inconclusive: the estimated coefficient of 1.26 is consistent with Result 1, but the t-statistic of 0.85

alternative theory, one might argue that bank debt financing of catastrophe-susceptible properties is inefficient, but perhaps less wealthy buyers simply substitute equity for bank debt and purchase these properties. This test relating quake risk to buyer wealth provides evidence against the alternative theory and supports the model in the paper. Given that loan size is jointly endogenous with buyer wealth, we exclude it from the regression.

indicates that the null hypothesis of a coefficient of zero cannot be rejected. This test appears to have too little power to provide evidence either in favor of or against Result 1. Evidence in other studies supports Result 1: Nakagawa, Saito and Yamaga (2004, 2005) find that earthquake risk reduces rents and land prices in Tokyo.

In a complementary test, we regress the log of sale price on quake risk, the log of earnings and the controls. As reported in column 2 of Table VI, the coefficient on quake risk is insignificant in this specification as well. In column 3 of Table VI, we display results from regressing the log of sale price on quake risk, the log of earnings, age, the interaction between quake risk and both the log of earnings and age and the usual controls. We find that the interactions between quake risk and the log of earnings and property age are both negative and significant, suggesting that quake risk has an impact on property prices primarily for larger and older properties. It may be that price effects of quake risk (which should be present for all properties) are more pronounced in more expensive transactions in part due to the difficulties we model in financing catastrophe-susceptible properties; the inability to find bank financing may have an especially strong impact in restricting the set of buyers for more valuable properties.

IV. The Impact of the Northridge Earthquake

We now turn to the impact of a specific event, the Northridge, California earthquake of January 17, 1994, on local markets.[20] In addition to the direct effects of the quake, earthquake insurance rates across California rose dramatically in the aftermath of the Northridge earthquake. In California, insurers must submit rate change requests to the state insurance commissioner for approval. The median requested (approved) change in commercial earthquake insurance rates in the year after the Northridge quake was 116% (96%).[21] Froot (2001) also documents an increase in the ratio of premium to expected loss for catastrophe reinsurance in the wake of the Northridge quake. These indirect effects of the earthquake suggest that quake risk may have distorted both prices and financing even in areas that experienced little physical damage. In particular, the earthquake may have reduced the competitiveness of the catastrophe insurance market. This shock to the supply

[20]Comerio et al. (1996), Ong et al. (2003), Loukaitou-Sideris and Kamel (2004) discuss the effects of the Northridge earthquake.

[21]The source for the rate change information is www.insurance.ca.gov. Press reports also describe large insurance price increases. See, for example, *Business Insurance*, July 4, 1994 and *Journal of Commerce*, April 19, 1994. In the capacity-constraints framework of Winter (1994) and Gron (1994), a capital loss by catastrophe insurers can lead directly to a shortage of insurance. In the Cummins and Danzon (1997) model, however, the price impact of a loss shock is theoretically ambiguous. The evidence described above suggests that in the case of the Northridge earthquake, the event led to a significant insurance market shock.

of commercial earthquake insurance was, however, relatively short-lived.[22]

We first consider the direct and indirect effects of the earthquake on local cap rates. Earnings are reported for the previous year, so the effect of the Northridge quake on cap rates largely reflects its effect on prices. We regress cap rates on the peak ground acceleration (PGA), a measure of quake intensity during the Northridge quake to measure the direct shaking effect of the Northridge earthquake. To capture the indirect effects of the Northridge quake, we examine the interactions of quake risk with the log of one plus the number of days following the Northridge quake on which the transaction took place (for transactions within one year of the quake) and an indicator for the year following the quake, and include the quake risk variable itself, which measures a property's susceptibility to future earthquake damage, irrespective of whether it was affected by the January, 1994 quake. The Northridge earthquake served as a significant shock to the supply of catastrophe insurance, and our interaction variables measure the extent to which this shock had a diminishing effect over time. We also include the log of the number of days following the quake (for transactions within one year of the quake) as an additional control.[23] The standard controls from the previous regressions, including census tract fixed effects, are included in the regression.

The first column of Table VII reports the results. Neither the PGA nor the interactions are significant. The indirect effect of the earthquake seems to have been small, as quake risk did not have a larger effect on property prices in the year after the Northridge quake.[24]

Result 6 states that the probability of bank financing increases with insurance market competitiveness. If the Northridge quake decreased the supply of catastrophe insurance, we should see relatively less bank financing for high catastrophe risk properties in its aftermath. We test this prediction by regressing the probability of bank financing on the previous set of variables for the direct and indirect impact of the quake. We find, as detailed in column two of Table VII, that the interaction of quake risk with the log of one plus the number of days after the quake (for properties sold within a year of the quake) is positive and significant (t-statistic = 2.57). The interaction of quake risk with an indicator for the year following the quake is negative and significant (t-statistic = -2.31). Considering an increase in quake risk from 0 to 0.2% for both a property sold 90 days

[22] For example, the median requested (and approved) rate change in 1996 was -5.7%. Froot (2001) shows that the premium to expected loss ratio declined to its pre-Northridge level by 1995. Further descriptions of moderation in insurance prices can be found in the accounts in *Business Insurance*, August 29, 1994 and *Journal of Commerce*, October 25, 1996.

[23] An indicator for the year following the quake is almost identical to the year indicator for 1994. Including it has no effect on the regression results.

[24] Bleich (2003) finds a 1-2 year effect of the Northridge quake on prices, but he considers the impact of the quake itself (i.e. PGA, which we control for), not the general quake risk that is our object of study.

the Northridge quake and for a property sold right after the quake, we find an interaction effect with a magnitude of 11.5 percentage points ($t-stat = 2.74$), indicating that quake risk especially reduced bank loan provision in the days following the quake.

For comparison, a linear probability model also yields a positive and significant coefficient on the interaction between quake risk and the log of one plus the number of days after the quake ($t-stat = 2.46$) and a negative and significant coefficient on the interaction between quake risk and the indicator for the year after the quake ($t-stat = -2.17$). The negative sign on the second interaction term indicates that shortly after the Northridge earthquake properties with high earthquake risk were particularly unlikely to be financed with bank loans. The positive sign on the first interaction term indicates that this effect moderated with time; as time passed the supplementary post-Northridge negative effect of quake risk on bank financing subsided. Considering the two interactions together, we find that the impact of the Northridge quake had essentially dissipated 3 months after the event. These results are consistent with Result 6: the catastrophic insurance supply shock generated by the Northridge quake reduced the provision of bank finance for high quake risk properties for approximately 3 months. The Northridge quake, however, had no significant long-term effect on the pricing or financing of quake risk. Consistent with this result, Froot (2001) finds no long-term effect of the Northridge earthquake on catastrophe premiums.

Column 3 of Table VII shows no significant increase in the size of banks making loans to high-quake-risk properties in Los Angeles county after January 1994. However, in column 4 we do find that local banks in Los Angeles county increased their lending to high-risk properties only gradually in the first two months following the Northridge earthquake.

Result 7 states that the average quake risk of bank-financed transactions is increasing in insurance market competitiveness, while the average quake risk of all-cash transactions is independent of insurance market conditions. To test these predictions, we regress the quake risk of all properties on the log of one plus the number of days following the Northridge quake on which the transaction took place (for transactions within one year of the quake), the PGA, and the standard controls. The results are displayed in the first column of Table VIII.[25] We find a positive and significant (t-statistic = 1.93) coefficient on the log of one plus the number of days following the quake, indicating that as the catastrophe insurance supply shock diminished, more high quake risk properties

[25] Most properties have zero quake risk, which suggests that Tobit may be an appropriate estimation technique. Our regressions, however, include a very large number of census tract fixed effects, which leads to biased inference in the Tobit model (Greene, 2004). We elect instead to use OLS. Results in the subsample of California properties (few of which have zero quake risk) are very similar to those reported here.

were purchased. This result is consistent with the theory, but Result 7 makes an even more precise prediction. Specifically, the quake risk of bank financed properties should increase as a supply shock recedes, while the quake risk of all-cash transactions will be unaffected. In the second column of Table VIII, we repeat the previous regression for the subsample of bank financed properties. We find that the average quake risk of bank-financed transactions increased significantly (t-statistic = 2.61) in the days following the quake. As shown in the third column of Table VIII, however, there is no effect on the average quake risk of all-cash transactions. These results are consistent with the predictions of Result 7.

A. Commercial Earthquake Insurance Market after the Northridge Earthquake

We find little additional effect of the Northridge earthquake on credit markets after a period of three months following the event. This finding is consistent with the rebound in the commercial earthquake insurance market after the Northridge quake. The Northridge earthquake had dramatically different impacts on the residential and commercial earthquake insurance markets in California. In 1994 and 1995 insurers, who faced a state law requiring them to offer earthquake insurance along with any homeowner's policy, in many cases elected to stop offering any new homeowner's coverage rather than being forced to offer earthquake insurance on terms they deemed unfavorable.[26] In response, the state government established the California Earthquake Authority as a publicly managed, largely privately funded organization that provides catastrophic residential earthquake insurance. No comparable state-managed organization was founded in the commercial earthquake insurance market.

In the aftermath of the Northridge earthquake, commercial earthquake insurers have increased their sophistication and made greater use of global reinsurance markets (Risk Management Solutions, 2004). The California Department of Insurance (2003) reports that in the period 1994-1999, commercial earthquake insurance coverage in the state increased, while residential coverage sharply decreased. In Los Angeles and Orange counties, for example, commercial coverage grew from a PML of $11.1 billion in 1994 to $13.6 billion in 1999. Residential coverage fell from $2.8 billion to $1.1 billion during the same time period. The reasonably quick return to health for the commercial earthquake market is confirmed by the press accounts cited above and is consistent with the short-term effects of the Northridge earthquake that we find in the data.

[26] In a behavioral analysis, Jaffee and Russell (2000) argue that consumers and firms updated their risk assessments differently post-Northridge, and that consumers were unwilling to purchase insurance at the prices firms offered.

V. Catastrophic Risk and Finance: Broader Implications

The model in Section I highlights two aspects of the interaction between bank credit and catastrophic risk insurance markets. First, banks are inefficient financiers of catastrophe-susceptible properties because they do not specialize in monitoring the implementation of safety-increasing investments (and they are poor at liquidating devastatingly-damaged collateral). Second, due to insufficient capital and market power by a small number of reinsurers, the catastrophe insurance market is inefficient. These two features, as we discuss below, are shared by a variety of catastrophic perils including hurricane, terrorism, and political risks. The theory implies that, as a consequence, in markets affected by any of these hazards increased catastrophic risk will be associated with reduced bank credit provision, decreased market participation by less wealthy investors and missed investment and development opportunities.

Our empirical work on earthquake risks broadly supports the predictions of the theory. Earthquake data offer two advantages for testing the theory. First, earthquake risks have been quantified clearly, which facilitates suitable tests. Second, earthquake risk exhibits significant highly localized variability, which enables the inclusion of census tract fixed effects in the tests, thereby minimizing the impact of unobservables. Our findings from the earthquake tests show the relevance of the theory and therefore support the application of the general theoretical predictions to other settings.

A. Hurricane Risk

Hurricane risk closely resembles that of earthquakes. Hurricanes, like earthquakes, cause terrible damage to properties that can be mitigated by appropriate preventative investments. The supply of hurricane insurance also exhibits inefficiencies similar to that of earthquake insurance (Froot, 2001). We should therefore expect hurricane risk to have similar effects to those we find for earthquakes.

To expand the scope of our empirical tests, in this section we examine the impact of hurricane risk on commercial property financing. The properties in our sample all face relatively low hurricane risk (all properties save one are described by AIR as having the same average annual loss from hurricanes: less than 0.1%).[27] AIR, however, also provided us with each property's percentile hurricane risk within its county and properties within Massachusetts, Maryland, Virginia, Texas, Georgia, New York and the District of Columbia exhibit variation in this relative hurricane risk. The hurricane risk assessment makes use of differential rates of wind speed dissipation over varying

[27] The Texas properties in the sample are largely located in Dallas and Austin, away from the coasts.

types of surface terrain and land cover (Source: www.air-worldwide.com). As an additional test of Result 2 relating catastrophe risk to the provision of bank financing, we regress an indicator for whether a property was financed with a bank loan on the property's percentile hurricane risk within its county and the previous controls, including census tract fixed effects. In untabulated results (available from the authors upon request), we find that the coefficient on hurricane risk is insignificant (t-statistic $= -1.09$). Given the generally low level of hurricane peril in our properties, this may reflect a lack of localized variation in hurricane risk within our sample. We thus repeat the previous regression, replacing the census tract fixed effects with zip code fixed effects. In this specification the coefficient on hurricane risk is negative and significant (t-statistic $= -2.26$), as predicted by Result 2. A one-standard deviation increase in relative hurricane risk reduces the probability of bank financing by 2.3 percentage points.

Results 2 and 6 also link the effects of catastrophe risk on financing to the competitiveness of the insurance market. Hurricane Andrew in 1992 had a dramatic effect on the supply of hurricane insurance (Froot, 2001), but only two properties in our sample with hurricane risk were sold in 1992. As an alternative measure of supply shocks to the hurricane insurance market, we consider the Guy Carpenter Catastrophe Insurance Price Index. This variable is limited in two respects. First, variations in a price index may reflect changes in demand rather than supply. Second, the index is national and conflates the prices of multiple types of catastrophe insurance. Nonetheless, the national price of catastrophe insurance is probably a reasonable proxy for the cost of all types of catastrophe insurance outside of markets such as the hurricane insurance market in Florida and the earthquake insurance market in California.[28] Those two markets are excluded from this test, so we proceed with the analysis despite the limitations of the variable. We regress an indicator for whether a property was purchased with a bank loan on hurricane risk, hurricane risk interacted with the Guy Carpenter Catastrophe Insurance Price Index, the previous controls and zip code fixed effects. (The Guy Carpenter Catastrophe Insurance Price Index is an annual index, so, given the use of year fixed effects, we do not include it in the regression.) The interaction between hurricane risk and the catastrophe insurance price index is negative and significant (t-statistic $= -2.73$). Considering an increase in hurricane risk percentile from 0 to 20 for both a property sold when the price index is at its median plus one standard deviation and for a property when the price index is at its median, we find an interaction effect with a magnitude of -1.2 percentage points ($t - stat = -2.73$), indicating

[28]The main driver for this index appears to have been Hurricane Andrew, which suggests that the index may place a higher weight on hurricane, rather than earthquake, insurance prices.

that hurricane risk reduces the probability of bank finance particularly in the years during which catastrophe insurance is especially expensive, consistent with Results 2 and 6, and provides another test of our theory for a different catastrophic risk setting.

B. Terrorism Risk

Terrorism risk shares the central characteristics of other catastrophic risks: enormous potential damages, specialized safety investments, difficulties in liquidating affected properties and inefficient supply of insurance. After the Sept. 11, 2001 terrorist attacks on the U.S., insurers and reinsurers quickly began to exclude terrorism risk from their policies (Hubbard, Deal and Hess, 2005). Consistent with the predictions of our theoretical model, commercial lending and development in major cities were significantly reduced (Serio, 2004). Terrorism risk is more difficult to optimally allocate than natural disaster risk for three reasons. First, terrorism risk is much harder to quantify. This ambiguity may lead to reduced provision of insurance (Hogarth and Kunreuther, 1985). Second, terrorism is endogenously determined by the actions of human agents. The optimal allocation of risk usually involves redistribution and trading, but in the case of terrorism risks this may lead to market manipulation (Poteshman, 2006). Third, the scale of damages from an act of terror is potentially greater than from a natural disaster.

The U.S. government passed the Terrorism Risk Insurance Act (TRIA) in 2002 to address the dislocations in the terrorism insurance market. TRIA requires insurers to offer terrorism coverage and institutes federal cost-sharing for terrorism damages. TRIA's proponents argue that it has created price stability in the terrorism risk insurance market and led to increased use of the insurance (as documented, for example, by the U.S. Department of the Treasury, 2005). There is also evidence that lenders require terrorism insurance for the great majority of commercial real estate loans (Cummins, 2006), consistent with our theoretical model and empirical findings for earthquake risk.[29] TRIA was renewed in 2005 and is up for renewal in 2007. The long-term inefficiencies in the supply of natural disaster catastrophic insurance and the arguments given above for why terrorism is even more difficult to insure than earthquakes or hurricanes indicate that the private market is unlikely to successfully supply sufficient terrorism insurance on its own. The findings in this paper therefore suggest two implications of a failure to renew TRIA. First, high profile properties and those located in high density areas (possible terrorism targets) are likely to suffer from reduced bank credit provision and market exit by less wealthy investors. Downtown areas in large U.S.

[29] We thank an anonymous referee for this point.

cities would be predicted to exhibit a substantial shift away from bank debt financing of properties and prices for larger properties may significantly decline. Second, redevelopment after an act of terrorism will be hampered by a particularly restricted supply of bank credit in the immediate post-event period. These effects may be especially severe in minority neighborhoods.

C. Political Risk

The political risk associated with an investment describes the probability of nationalization, currency controls or other government action that reduces the project value. This risk, which is typically most salient in emerging markets, has the potential to generate huge losses and the risk assessment is uncertain, so the supply of political risk insurance, like that of other catastrophic risks, is quite restricted (Hamdani et al., 2005). The providers of political risk insurance (particularly the public agencies such as the Multilateral Investment Guarantee Agency of the World Bank and the Overseas Private Development Corporation of the U.S. government) are typically very knowledgeable about foreign countries and skilled at negotiating with the local authorities. In the terms of our model, these insurers are better at ensuring that all necessary political precautions are undertaken and they also specialize in liquidating investments adversely affected by political risk.

Our model and empirical work indicate that political risk insurance can serve two important functions. First, our results tying investment and market participation to the efficiency of insurance markets imply that more financially constrained and smaller firms will be significantly more likely to invest in developing foreign countries if fairly priced political risk insurance is available. Second, there is growing interest in emerging market debt (Erb, Harvey, Viskanta, 2000) and our findings linking bank loan provision to the availability of catastrophic insurance suggest that investors will be more willing to provide debt financing to at-risk firms when it is accompanied by political insurance.[30] Hence, a well-functioning political risk insurance market may be especially important in promoting the issuance of emerging market corporate bonds.

[30] As our model makes clear, the monitoring problem faced by lenders may make them unwilling to supply debt in the absence of insurance, irrespective of the promised interest rate. Alternatively, the lack of insurance may increase the necessary promised rate to a level that borrowers regard as unacceptable.

VI. Conclusion

We present a model in which banks are inefficient in financing properties facing catastrophic risk because they do not specialize in monitoring the implementation of safety-improving investments. This function is best performed by insurers, but imperfections in the supply of catastrophe insurance can distort real estate markets by limiting the provision of bank credit and preventing positive NPV projects from being undertaken.

An empirical analysis of the effects of earthquake risk provides evidence in support of the theory, suggesting that inefficiencies in the catastrophe insurance market are reducing the provision of bank credit, limiting the market participation of less wealthy investors, and hampering neighborhood revitalization in disadvantaged areas. We also analyze the 1994 Northridge earthquake, which led to a reduction in bank lending to high-risk properties, but only for about three months. We find no significant longer-term financing or pricing effects arising from the Northridge earthquake. Thus, the large shock to the supply of earthquake insurance arising from the earthquake exacerbated the general degree of inefficiency in the bank financing of earthquake risk, but for only a short period of time.

Our model presents a framework for analyzing broad classes of catastrophic risks including hurricane, terrorism and political perils, and our empirical work suggests implications for these markets. We show that hurricane risk, like that of earthquakes, reduces bank financing. We argue that terrorism and political risk share the central features of natural disaster risk and may be even more subject to an insufficient supply of insurance. Our findings suggest that a lack of terrorism insurance is likely to cause a shift away from bank debt financing in downtown U.S. cities and to lead to the exit from these areas of less wealthy investors. A restricted supply of political risk insurance will discourage foreign investments by financially-constrained firms and depress emerging market corporate bond issuance.

Exposure to catastrophic risks, both natural and unnatural, continues to grow due to population shifts to at-risk areas, global warming, and changing political dynamics. Continued inefficiencies in the sharing of catastrophic risks and their effects on broader capital markets may have implications for long-term growth in a wide variety of countries.

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Appendix

We propose (and later confirm) that $V_t = kC_t$ for some constant k. Under this assumption V_t has the same risk as C_t and may also be discounted at the rate r. The value of the property at any given time s must satisfy:

$$V_s = p\frac{E[C_{s+1} + V_{s+1}|C_s]}{1+r} + (1-p)\frac{E\left[R_{s+1}V_{s+1}|C_s\right]}{1+r}. \tag{3}$$

The equations $V_x = kC_x$ and $E[C_{x+1}|C_x] = C_x$ for all x then imply that

$$kC_s = p\frac{(1+k)C_s}{1+r} + (1-p)\frac{E[R]kC_s}{1+r},$$

which simplifies to

$$k(1 + r - p - (1-p)E[R]) = p. \tag{4}$$

This equation shows that k is a constant, so the valuation equation (3) is indeed satisfied by our proposed solution $V_t = kC_t$.

Proof of Result 1:

The cap rate is $\frac{1}{k} = \frac{r+q}{p}$. We calculate

$$\frac{d\left(\frac{1}{k}\right)}{dq} = \frac{1}{p} - \frac{(r+q)}{p^2}\frac{dp}{dq} \geq 1.$$

Model of Imperfect Bank Information, Safety Investments and Borrower Risk-Shifting

We present a model in which property owners have the ability each period to make a positive NPV safety-improving investment. Banks know little about properties and are not experts in these investments, so banks cannot monitor the property owners. The safety-improving investment reduces risk, so owners who have borrowed from a bank may choose to forego the investment.

We assume that each period s, the property owner observes C_s and then decides whether or not to make a safety-enhancing investment. If the owner declines to make the investment, then the property value and cash flow are as described earlier: with probability p, the property value is V_s and the cash flow is C_s, and with probability $(1-p)$, there is no cash flow and the property value is R_sV_s. For simplicity we assume that $R_s = 0$ and that the $\{\alpha_t\}$ have full support on a range $(0, k_1)$ for $k_1 > 0$.

If the owner makes the investment, the catastrophe risk is mitigated. The property now yields a total cash flow and value of $p(C_s + V_s) + (1-p)\gamma V_s$ with probability one, where $\gamma \in (0, 1)$. This payoff is lower than the payoff without the investment in the event of no catastrophe, due to the cost of the repairs (this follows from $\gamma < 1$). The assumption that $\gamma > 0$ ensures that making the investment is positive NPV.

It is clear that unconstrained owners who do not borrow will make the repair, and the property valuation will reflect this fact. In analogy to our earlier argument:

$$V_s = \left[\frac{p}{1+r-p-\gamma(1-p)}\right] C_s.$$

We now consider the case in which a property with value V_s and catastrophe risk p is financed with bank debt with face value m and market value $L(m, V_s, p)$. For a given current property market value V_s, we denote by ϵ the risk-neutral probability associated with next period's market value V_{s+1}, and we define r_f to be the risk-free rate. If the investment is not undertaken, the value of the debt is

$$\frac{p \int min\{\frac{V_{s+1}(1+r-\gamma(1-p))}{p}, m\}\epsilon(V_{s+1})dV_{s+1}}{1+r_f}. \tag{5}$$

If the investment is undertaken, the value of the debt is

$$\frac{\int min\{V_{s+1}(1+r), m\}\epsilon(V_{s+1})dV_{s+1}}{1+r_f}. \tag{6}$$

In considering whether or not to make the investment, the owner evaluates the increased equity value that he would enjoy. We assume that the owner only makes the investment when it yields him a positive benefit. This is equal to the increase in property payoff minus the increase in debt value. If $m \geq p(C_{s+1} + V_{s+1}) + V_{s+1}\gamma(1-p) = V_{s+1}(1+r)$, the owner will have a zero equity value under the safety investment, so he will not make the investment. For $m \leq V_{s+1}(1+r)$, the equity gain from making the investment is $V_{s+1}\gamma(1-p) - m(1-p)$. The owner will thus make the investment if and only if $m < V_{s+1}\gamma$.

We define $V^*(m) = \frac{m}{\gamma}$. The market value of the debt will reflect the fact that the owner will only invest if $V_{s+1} > V^*(m)$. The continuous distribution of V_{s+1} and the continuity of (5) and (6) in m, guarantee that $L(m, V_s, p)$ is continuous in m. We define $D(V_s, L_1, p)$ to be the lowest value of $m \geq 0$ such that $L(m, V_s, p) = L_1$. (If no such value exists, the property cannot be financed with a bank loan of value L_1. If $V_s - w = L_1$ for such an L_1, we set the resultant loss of value $loss(w, V_s, p) = \infty$.)

We now show that for $p_2 > p_1$, if $D(V_s, L_1, p_1)$ exists, then $D(V_s, L_1, p_2) \leq D(V_s, L_1, p_1)$. We note $L(D(V_s, L_1, p_1), V_s, p_2) \geq L(D(V_s, L_1, p_1), V_s, p_1)$, because the investment threshold is independent of p, (6) is independent of p and (5) is increasing in p. The result then follows from the continuity of $L(m, V_s, p_2)$ in m. We conclude that $D(V_s, L_1, p)$ is decreasing in p. It also follows from the continuity of $L(m, V_s, p)$ in m that $D(V_s, L_1, p)$ is increasing in L_1.

A value loss is incurred if the investment is not undertaken ($V_{s+1} \leq V^*(m)$). The amount of the loss is $\gamma(1-p)V_{s+1}$. We thus have

$$loss(w, V_s, p) = \int_0^{V^*(D(V_s, V_s - w, p))} \gamma(1-p)V_{s+1}\epsilon(V_{s+1})dV_{s+1}. \tag{7}$$

We showed that $D(V_s, L_1, p)$ is decreasing in p and increasing in L_1, so it is clear from (7) that $loss(w, V_s, p)$ is decreasing in p and w. This is Property 1. If $V_s > w$ and $p < 1$ then $D(V_s, V_s - w, p) > 0$ and hence $loss(w, V_s, p) > 0$, because the $\{\alpha_t\}$ have full support on a range $(0, k_1)$ (so with positive probability, $V_{s+1} < D(V_s, V_s - w, p)$). It is clear that $loss(w, V_s, 1) = 0$ and $D(V_s, 0, p) = 0$, so $loss(V_s, V_s, p) = 0$. This is Property 2.

Role of Insurance

We assume that the insurer can observe whether or not the safety-enhancing investment have been implemented and may condition the insurance premium on the presence or absence of the investment. If the investment has been made, the insurance will pay off $C_{s+1} + (1-\gamma)V_{s+1}$ in the event of a catastrophe. The market value of this insurance is $\frac{E[C_{s+1}+(1-\gamma)V_{s+1}|V_s]}{1+r}$. If the investment has not been made, the insurance will pay off $C_{s+1} + V_{s+1}$ in the event of a catastrophe and will have a market value of $\frac{E[C_{s+1}+V_{s+1}|V_s]}{1+r}$. In both cases, the final payoff of the property is $C_{s+1} + V_{s+1}$, so in the presence of insurance, the investment decision by the owner has no risk-shifting implications.

We assume that the insurer makes a bid with two specified premia for the two cases of investment and no investment. We will show that, in equilibrium, the owner will choose to make the investment. We assume that the premium for the no investment case is given by $\frac{E[C_{s+1}+V_{s+1}|V_s]}{1+r}+mar_1$, where mar_1 is a mark-up charged by the insurer. Suppose for a contradiction that the owner elects not to make the investment and to pay this no-investment premium.

If the insurer were to offer a premium in the investment case of $\frac{1}{2}\left[\frac{E[C_{s+1}+V_{s+1}|V_s]}{1+r}+\frac{E[C_{s+1}+(1-\gamma)V_{s+1}|V_s]}{1+r}\right]+$ mar_1, the owner would prefer to make the investment, since this premium is lower than the no-investment premium. This investment premium, however, yields the insurer a net mark-up of $mar_1+\frac{1}{2}\left[\frac{E[C_{s+1}+V_{s+1}|V_s]}{1+r}-\frac{E[C_{s+1}+(1-\gamma)V_{s+1}|V_s]}{1+r}\right]>mar_1$. That is, this investment case premium benefits both the insurer and the property owner. It therefore cannot be that the insurer will offer a set of premia that induce the owner not to make the investment. We conclude that in the presence of insurance, the owner will always prefer to make the investment and, as a result, there will be no efficiency loss.

Proof of Result 2. If the investor is unconstrained, the transaction is consummated in all cases in an all-cash deal. If the investor is constrained, he will only purchase the property with a bank loan. There are three possibilities. With probability $(1-n)^2$, no insurers bid and the investor purchases the property only if $b \geq loss(w, V_s, p)$. In this case the property is purchased without insurance. With probability $2n(1-n)$ one insurer bids, the bid is $mar = min\{b^*, w_L, loss(w_L, V_s, p)\}$, and the investor purchases the property only if $b \geq min\{b^*, w_L, loss(w_L, V_s, p)\}$. In this case the property is purchased with insurance. With probability n^2, two insurers bid, $mar = 0$ and the investor always purchases the property with insurance. Thus probability that a transaction is financed with bank debt is given by

$$\frac{(1-l)\left((1-n)^2(1-F_b(loss(w,V_s,p)))+2n(1-n)(1-F_b(min\{b^*,w_L,loss(w_L,V_s,p)\}))+n^2\right)}{(1-l)\left((1-n)^2(1-F_b(loss(w,V_s,p)))+2n(1-n)(1-F_b(min\{b^*,w_L,loss(w_L,V_s,p)\}))+n^2\right)+l}. \tag{8}$$

The result follows from Property 1 that $loss(w_L, V_s, p)$ is decreasing in p.

Proof of Result 3.

The average wealth of the purchasing investor is given by

$$\frac{w_L(1-l)\left((1-n)^2(1-F_b(loss(w,V_s,p)))+2n(1-n)(1-F_b(min\{b^*,w_L,loss(w_L,V_s,p)\}))+n^2\right)+w_H l}{(1-l)\left((1-n)^2(1-F_b(loss(w,V_s,p)))+2n(1-n)(1-F_b(min\{b^*,w_L,loss(w_L,V_s,p)\}))+n^2\right)+l}. \tag{9}$$

The result follows Property 1.

Proof of Result 4. If the insurance market is perfectly competitive, insurance is provided at fair value, and purchasing insurance allows the constrained investor to avoid all liquidation costs. For debt with any face value $m > 0$, if $(1-p) > 0$, Property 2 shows that these liquidation costs are strictly positive, so all constrained investors will purchase insurance. If the insurance market is imperfectly competitive, the proof of Result 2 showed that the probability that a bank-financed purchase carries insurance is given by

$$\frac{(2n(1-n)(1-F_b(min\{b^*, w_L, loss(w_L, V_s, p)\})) + n^2)}{((1-n)^2(1-F_b(loss(w, V_s, p))) + 2n(1-n)(1-F_b(min\{b^*, w_L, loss(w_L, V_s, p)\})) + n^2)}. \tag{10}$$

The result follows from the fact that $loss(w_L, V_s, p)$ is decreasing in p.

Proof of Result 5. The probability of a transaction is given by

$$(1-l)\left((1-n)^2(1-F_b(loss(w, V_s, p))) + 2n(1-n)(1-F_b(min\{b^*, w_L, loss(w_L, V_s, p)\})) + n^2\right) + l.$$

The result follows from the fact that $loss(w_L, V_s, p)$ is decreasing in p.

We now assess the impact on a change in the competitiveness of the insurance market in the composition of properties sold in the market. We suppose that p is a random variable with cdf F_P and pdf f_P.

Proof of Result 6. The result follows from (8) and from the fact that for $1 \geq b \geq a$,

$$\frac{d}{dn}(a(1-n)^2 + 2bn(1-n) + n^2) = 2(n - nb + b(1-n) - a(1-n)) \geq 0.$$

Proof of Result 7. Unconstrained investors pay all cash and do not suffer liquidation costs, so the average catastrophic risk of all-cash transactions is $E[1-p]$. Constrained investors require bank financing. The pdf $h_1(p, n)$ of bank-financed sales for a given n is

$$h_1(p, n)$$

$$= \frac{f_P(p)\left((1-n)^2(1-F_b(loss(w_L, V_s, p))) + 2n(1-n)(1-F_b(min\{b^*, w_L, loss(w_L, V_s, p)\})) + n^2\right)}{\int f_P(x)\left((1-n)^2(1-F_b(loss(w_L, V_s, p))) + 2n(1-n)(1-F_b(min\{b^*, w_L, loss(w_L, V_s, p)\})) + n^2\right) dx}$$

We will show that for $n_1 \geq n_2$, $h_1(p, n_2)$ dominates $h_1(p, n_1)$ in the sense of the monotone likelihood ratio property (MLRP). That is sufficient to show $\int(1-p)h_1(p, n_1)dp \geq \int(1-p)h_1(p, n_2)dp$. We require that

$$r(p) = \frac{(1-n_1)^2(1-F_b(loss(w_L,V_s,p))) + 2n_1(1-n_1)(1-F_b(min\{b^*,w_L,loss(w_L,V_s,p)\})) + n_1^2}{(1-n_2)^2(1-F_b(loss(w_L,V_s,p))) + 2n_2(1-n_2)(1-F_b(min\{b^*,w_L,loss(w_L,V_s,p)\})) + n_2^2}$$

be decreasing in p. We first note that

$$r_1(p) = \frac{Aj_1(p)+B}{Cj_1(p)+D} \tag{11}$$

is decreasing in p if $j_1(p)$ is increasing in p and $\frac{B}{D} \geq \frac{A}{C}$. For p such that $loss(w_L,V_s,p) \leq min\{b^*,w_L\}$, $r(p) = \frac{Aj_1(p)+B}{Cj_1(p)+D}$, where $j_1(p) = 1-F_b(loss(w_L,V_s,p))$ is increasing in p and $\frac{B}{D} = \frac{n_1^2}{n_2^2} \geq 1 \geq \frac{1-n_1^2}{1-n_2^2} = \frac{A}{C}$. For p such that $loss(w_L,V_s,p) \geq min\{b^*,w_L\}$ but such that $loss(w_L,V_s,p) < \infty$ (i.e. such that $loss(w_L,V_s,p) \leq w_L$), $r(p) = \frac{Aj_1(p)+B}{Cj_1(p)+D}$, where $j_1(p) = 1-F_b(loss(w_L,V_s,p))$ and $\frac{B}{D} = \frac{n_1^2+2n_1(1-n_1)(1-F_b(min\{b^*,w_L\}))}{n_2^2+2n_2(1-n_2)(1-F_b(min\{b^*,w_L\}))} \geq 1 \geq \frac{(1-n_1)^2}{(1-n_2)^2} = \frac{A}{C}$. The function r is discontinuous at p^* such that $loss(w_L,V_s,p^*) = w_L$. We note, however, that for $p < p^*$,

$$r(p) = \frac{2n_1(1-n_1)(1-F_b(min\{b^*,w_L\})) + n_1^2}{2n_2(1-n_2)(1-F_b(min\{b^*,w_L\})) + n_2^2}$$

$$\geq \frac{(1-n_1)^2(1-F_b(w_L)) + 2n_1(1-n_1)(1-F_b(min\{b^*,w_L\})) + n_1^2}{(1-n_2)^2(1-F_b(w_L)) + 2n_2(1-n_2)(1-F_b(min\{b^*,w_L\})) + n_2^2} = r(p^*)$$

since $\frac{n_1^2+2n_1(1-n_1)(1-F_b(min\{b^*,w_L\}))}{n_2^2+2n_2(1-n_2)(1-F_b(min\{b^*,w_L\}))} \geq 1 \geq \frac{(1-n_1)^2}{(1-n_2)^2}$.

Discussion of Omitted Variables

We now turn to the hypothesis that some unobserved variable is jointly determining quake risk and bank loan provision. Earthquake risk itself is based on soil conditions and relative proximity to fault lines (which are arguably exogenous), so the endogeneity concern here is one of matching of types of properties to types of buyers or markets. Are local markets where quake risk is high more financially constrained? Are the types of owners of high quake risk properties different along other unobservable dimensions that might also affect the probability of bank financing? Such unobservable effects may create an omitted variable bias that could erroneously highlight a significant role for quake risk in predicting bank loan provision when no such role exists, or could generate what appears to be no role for quake risk when in fact such risks are taken into account by lenders. The sign of the potential bias is ambiguous.

To address the issue of omitted variable bias, we consider the following. First, we employ census tract fixed effects to difference out unobservables at a level much finer than the level at which local financial markets operate. In addition, since a census tract is designed to be homogeneous with respect to population characteristics, economic status, and living conditions (source: United States Census Bureau), the use of tract fixed effects helps to difference out other unobservables about the local population. Local debt market conditions are clearly highly uniform within a census tract (Kwast, Starr-McCluer, and Wolken, 1997), so the financing environment is unlikely to be driving the micro-level variation we study.[31]

Second, the loans we consider are non-recourse, meaning that the lender may only seek the collateral value and *not* any other assets of the borrower in the event of default. The non-recourse feature of this market implies that borrower quality should be of far less importance than collateral value.

Third, the bank loan term results also help address omitted variable concerns. For example, if different types of borrowers select properties (within a given census tract) with different risk characteristics (e.g., higher quality borrowers may avoid high quake risk properties), then we should expect quake risk to not only affect bank loan provision, but bank loan terms as well. Any unobservable quality differences of borrowers or properties that might be related to quake risk and loan provision, would almost certainly also be related to the financing terms the bank is willing to supply. Omitted variable problems of this type would predict greater bank loan provision *and* better loan terms. We find, however, that quake risk is only related to the probability of obtaining a bank loan, and is unrelated to any loan term, so unobservable quality differences are unlikely to explain our findings.

Fourth, the lack of a significant relation between quake risk and seller financing also weighs against an omitted variable explanation relating to unobserved borrower or property quality, which would presumably be relevant to any lender (bank or seller). A direct role for quake risk is the only plausible explanation for these differential effects across lender types.

Last, we also control for the current sale price of the property in an attempt to isolate the component of quake risk related to liquidation value. Variables related to market value and quake risk simultaneously should be captured by the sale price and, in fact, may understate the effect of quake risk on loan provision. Potential omitted variables affecting quake risk and financing on a specific property within a census tract, property type, and year *and* controlling for sale price and other attributes, are difficult to envision.

[31] The standard definition of the local banking market in the literature (e.g., Berger, Demsetz, and Strahan, 1999) is the local Metropolitan Statistical Area (MSA) or non-MSA county.

Table I:
Summary Statistics of Commercial Real Estate Property Transactions, Quake Risk, the Effects of the Northridge 1994 Earthquake, and CMBS Issuances

Panel A: Summary statistics of *COMPS* sale and loan transactions

	Mean	Median	Standard deviation	1^{st}%	99^{th}%
Sale price ($US)	2,204,878	590,000	10,609,900	112,000	30,047,860
Capitalization rate (%)	10.02	9.75	2.81	4.57	18.35
Property age (years)	37.74	31	32.95	1	109
Loan size (% of price)	75.49	77.27	16.28	17.24	100
Interest rate (%)	8.28	8.25	1.41	5	12
Maturity (years)	16.06	15	10.79	0.50	30

Panel B: Summary statistics of *COMPS* quake risk and Northridge PGA

	Mean	Median	Standard Deviation
Quake risk - all properties	0.07	0	0.12
Quake risk - CA properties	0.19	0.20	0.12
Quake risk - LA county properties	0.25	0.20	0.07
Northridge PGA - all properties	7.71	0	14.13
Northridge PGA - CA properties	20.46	18.72	16.40
Northridge PGA - LA county properties	26.78	23.08	13.52

Panel C: Summary statistics of S&P CMBS Transactions

	Number
CMBS issuers	24
CMBS transactions	50
Individual properties	482
High PML properties	183
Insured properties	169
Insured High PML properties	98

Panel A reports the distributional characteristics of the property transactions in the *COMPS* database over the period January 1, 1992 to March 30, 1999. The mean, median, standard deviation, and one and 99 percentiles of sale price, capitalization rate (net operating income divided by sales price), property age, loan size (loan-to-value), loan interest rate, and loan maturity are reported. Panel B reports the mean, median and standard deviation of average annual loss due to earthquake risk (quake risk) from the AIR database and peak ground acceleration (PGA) during the Northridge (1994) earthquake from the USGS database across all properties in the *COMPS* database. Panel C reports the number of commercial mortgage-backed securities (CMBS) issuers, total CMBS transactions, total number of earthquake zone properties included in the CMBS transactions, the number of earthquake zone properties with probable maximum loss above 20% (High PML), the number of earthquake zone properties with earthquake insurance and the number of insured High PML properties.

Table II:
Earthquake Risk and Insurance for Securitized Loans

Dependent variable	Quake insurance provided?	Quake insurance provided?	Quake insurance provided?
N	*482*	*482*	*482*
High quake risk	1.51	1.41	1.00
	(7.41)	(2.55)	(3.04)
	[35.9%]	[33.8%]	[24.4%]
Fixed effects?			
Year	Yes	Yes	Yes
CMBS issuer	No	Yes	No
CMBS transaction	No	No	Yes
Estimation method	*Logit*	*Logit*	*Logit*
Pseudo R^2	0.09	0.09	0.02

Results from the regressions of an indicator for whether earthquake insurance was provided for the property securing the loan on an indicator for properties with probable maximum loss above 20% (High PML), year dummies and transaction attributes. The data is drawn from the S&P CMBS transactions database. The regressions are estimated via binary fixed effects (conditional) logistic regression (Logit), as described, with robust t-statistics reported in parentheses. The increase in probability of earthquake insurance being provided for High quake risk properties (relative to the mean probability) in given in square brackets. The reported R^2 is McFadden's pseudo R^2.

Table III:
Earthquake Risk and Commercial Real Estate Financing Terms

Dependent variable	Bank loan provided?	Interest rate	Leverage	Seller financing provided?
Sample	*All*	*Bank loans*	*Bank loans*	*All*
N	*32,618*	*3,943*	*11,478*	*29,075*
Quake Risk	-2.6313	0.8337	-0.0279	0.4816
	(-2.83)	(0.64)	(-0.33)	(0.43)
Brokered	0.5620	-0.0207	0.0001	-0.1725
	(18.62)	(-0.35)	(0.04)	(-4.46)
Broker Buyer	0.1520	-0.0395	-0.0009	0.4196
	(1.76)	(-0.38)	(-0.10)	(4.07)
Log (Price)	-0.0094	-0.0144	0.0142	-0.2271
	(-0.61)	(-0.42)	(3.39)	(-10.18)
Corporate Buyer	-0.1878	0.0415	0.0001	-0.2213
	(-5.59)	(0.63)	(1.15)	(-4.94)
Property Crime	-0.0002	-0.0015	0.0000	-0.0021
	(-0.27)	(-1.02)	(-0.57)	(-2.59)
Personal Crime	-0.0002	0.0015	0.0001	0.0021
	(-0.44)	(1.35)	(1.08)	(2.70)
Age	-0.0017	-0.0001	-0.0027	0.0048
	(-2.93)	(-0.20)	(-2.76)	(5.39)
Log (Buyer Distance)	-0.0908	-0.0103	0.0013	-0.0945
	(-12.70)	(-0.74)	(1.66)	(-9.64)
Log (Seller Distance)	-0.0002	0.0187	0.0160	-0.0208
	(-0.02)	(1.62)	(1.57)	(-1.76)
Development	0.0541	0.1852	-0.0001	0.0451
	(0.80)	(1.10)	(-0.73)	(0.50)
Maturity		-0.0101	0.0024	
		(-4.18)	(1.00)	
Floating?		-0.3463	0.0841	
		(-5.89)	(6.91)	
SBA?		-0.3900		
		(-1.19)		
Loan Size/Price		-0.3771		
		(-1.65)		
Log(Bank Assets)		-0.0605	-0.0009	
		(-6.14)	(-1.39)	
Fixed effects?				
Census tract	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Property type	Yes	Yes	Yes	Yes
Estimation method	*Logit*	*OLS*	*OLS*	*Logit*
R^2	0.19	0.72	0.32	0.17

Results from the regressions of an indicator for whether a bank loan was provided (first column), the interest rate on an extended bank loan (second column), the leverage (loan size divided by sale price) on an extended bank loan (third column) and an indicator for whether seller financing was provided (fourth column) on quake risk and property and transaction attributes. The data is drawn from the *COMPS* database. The regressors with reported coefficients are the average annual loss due to earthquake risk (obtained from AIR), indicators for whether a broker arranged the transaction and for whether the buyer was a broker, the log of the sale price, an indicator for corporate buyers, the 1990 property and personal crime risks (obtained from CAP Index), the age of the property, the log of buyer and seller distances from the property, an indicator for development projects, loan maturity in years, indicators for floating rate and Small-Business-Administration guaranteed loans, leverage and log of bank assets. The seller financing regression includes the log of the median home value in the seller's zip code and indicators for sellers that are located out of town, sellers that are corporations and sellers that are banks as additional regressors. All regressions include fixed effects for property type, year and census tract, with coefficients unreported for brevity. The regressions are estimated via binary logistic regression (Logit) or ordinary least squares (OLS), as described, with robust t-statistics reported in parentheses. Reported R^2 for Logit specifications is McFadden's pseudo R^2.

Table IV:
Cross-sectional Effects of Earthquake Risk on Provision of Bank Financing

Dependent variable	Bank loan provided?	Bank loan provided?	Bank loan provided?	Bank loan provided?	Bank loan provided?
Sample	*All*	*Tract value available*	*All*	*All*	*Age available*
N	*32,618*	*22,924*	*32,618*		*25,012*
Quake Risk	-2.6626	7.9693	-3.7203	-1.2629	-0.8694
	(-2.86)	(0.17)	(-3.88)	(-3.92)	(-0.86)
(Quake Risk) * (Insurance Firm)	5.6787				
	(2.20)				
(Quake Risk) *(% African-American)		-54.8223			
		(-1.98)			
(Quake Risk)*Log (Median Home Value)		0.2582			
		(0.10)			
(Quake Risk)*Log (Median Income)		-0.5638			
		(-0.14)			
(Quake Risk) *(% Unemployed)		-55.9338			
		(-1.25)			
(Quake Risk) *(% HS Graduate)		-2.4440			
		(-0.69)			
(Quake Risk) * Brokered			1.4523		
			(5.86)		
(Quake Risk) * Brokered (Inst.)				1.1873	
				(3.40)	
(Quake Risk) * Age					-0.0540
					(-8.62)
Insurance Firm	-1.4721				
	(-4.21)				
Brokered	0.5615	0.6617	0.4560		0.5900
	(18.60)	(17.90)	(13.00)		(16.92)
Brokered (Inst.)				0.2941	
				(1.03)	
Age	-0.0017	-0.0016	-0.0016	-0.0003	-0.0006
	(-2.92)	(-2.48)	(-2.83)	(-1.91)	(-1.00)
Fixed effects?					
Census tract	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Property type	Yes	Yes	Yes	Yes	Yes
Estimation method	*Logit*	*Logit*	*Logit*	*2SLS*	*Logit*
Pseudo R^2	0.19	0.20	0.19		0.16

Results from the regressions of an indicator for whether a bank loan was provided on quake risk and property and transaction attributes. The data is drawn from the *COMPS* database. The regressors with reported coefficients are the average annual loss due to earthquake risk (obtained from AIR), property age, indicators for whether an insurance firm (insurer or insurance broker) purchased the property, for whether a broker arranged the transaction, an instrumented indicator for whether the transaction was brokered (using market thickness as an instrument) and interactions between the average annual loss due to earthquake risk and the following variables: insurance firm purchaser, property age, the fraction of the property's census tract population that is African-American, the log of median home value in the property's census tract, the log of median income in the property's census tract, the fraction of the tract's population that is unemployed, the fraction of the tract's population that is a high school graduate, (all tract-level variables obtained from the 2000 census), an indicator for brokered transactions, an instrumented indicator for brokered transactions and property age. All regressions include an indicator for whether the buyer was a broker, the log of the sale price, an indicator for corporate buyers, the 1990 property and personal crime risks (obtained from CAP Index), the log of buyer and seller distances from the property, an indicator for development projects and fixed effects for property type, year and census tract, with coefficients unreported for brevity. The regressions are estimated via binary logistic regression (Logit) or 2SLS with t-statistics reported in parentheses. Reported R^2 for Logit specifications is McFadden's pseudo R^2. For 2SLS, R^2 is not reported.

Table V:
Earthquake Risk and Selection of Buyers and Banks

Dependent variable	Log of Median Home Value in Buyer's Zip Code	% Deposits in county	Log of bank assets
Sample	*Non-corporate buyers*	*Bank deposits available*	*Bank assets available*
N	*17,967*	*7,487*	*11,478*
Quake Risk	0.4346	0.4360	0.6033
	(2.06)	(1.65)	(0.34)
Brokered	0.0322	-0.0218	0.0777
	(4.15)	(-1.74)	(1.22)
Broker Buyer	0.0047	0.0038	-0.1009
	(0.23)	(0.14)	(-0.61)
Log (Price)	0.0292	-0.0010	0.4168
	(5.36)	(-0.05)	(3.30)
Corporate Buyer		-0.0063	-0.0168
		(-0.47)	(-0.23)
Property Crime	0.0000	0.0000	-0.0004
	(-0.10)	(-0.12)	(-0.25)
Personal Crime	-0.0001	0.0001	-0.0008
	(-0.40)	(0.66)	(-0.67)
Age	0.0000	0.0000	-0.0004
	(0.16)	(0.11)	(-0.35)
Log (Buyer Distance)	0.0813	-0.0045	0.0175
	(28.26)	(-1.55)	(1.06)
Log (Seller Distance)	0.0017	-0.0055	0.0016
	(0.93)	(-2.27)	(0.12)
Development	-0.0334	-0.0051	-0.3017
	(-1.56)	(-0.15)	(-2.01)
Log(Loan Size)		-0.0265	-0.0488
		(-1.28)	(-0.40)
Fixed effects?			
Census tract	Yes	Yes	Yes
Year	Yes	Yes	Yes
Property type	Yes	Yes	Yes
R^2	0.47	0.47	0.37

Results from the regressions of the median home value in the buyer's zip code (from the 2000 census), the ratio of in-county deposits to total deposits for the bank extending the loan and the log of the total assets of the bank extending the loan on quake risk and property and transaction attributes. The regressors with reported coefficients are the average annual loss due to earthquake risk (obtained from AIR), indicators for whether a broker arranged the transaction and for whether the buyer was a broker, the log of the sale price (excluded from the cap rate and sale price regressions), an indicator for corporate buyers, the 1990 property and personal crime risks (obtained from CAP Index), the age of the property, the log of buyer and seller distances from the property and an indicator for development projects. In the second and third columns, the log of loan size is included as an additional control. All regressions include fixed effects for property type, year and census tract, with coefficients not reported for brevity. All regressions are estimated via ordinary least squares (OLS) with robust t-statistics reported in parentheses.

Table VI:
Earthquake Risk and Commercial Real Estate Prices

Dependent variable	Cap rate	Log of price	Log of price
N	*12,444*	*12,444*	*12,444*
Quake Risk	1.2609	-0.1342	5.3954
	(0.86)	(-1.00)	(12.96)
Log (Earnings)		0.9255	0.9503
		(286.92)	(273.58)
(Quake Risk) * Log (Earnings)			-0.3468
			(-14.12)
(Quake Risk) * Age			-0.0035
			(-3.13)
Brokered	0.3786	-0.0366	-0.0336
	(5.71)	(-5.91)	(-5.52)
Broker Buyer	0.1068	-0.0079	-0.0073
	(0.80)	(-0.61)	(-0.58)
Corporate Buyer	0.2281	0.0255	0.0270
	(3.27)	(3.85)	(4.12)
Property Crime	-0.0023	0.0002	0.0002
	(-1.62)	(1.50)	(1.33)
Personal Crime	0.0037	-0.0004	-0.0004
	(2.84)	(-3.27)	(-3.14)
Age	0.0053	-0.0011	-0.0009
	(3.21)	(-7.13)	(-4.68)
Log (Buyer Distance)	0.0424	0.0035	0.0025
	(3.42)	(2.82)	(2.05)
Log (Seller Distance)	0.0430	-0.0016	-0.0019
	(3.59)	(-1.37)	(-1.67)
Development	0.0938	0.0098	0.0090
	(0.55)	(0.60)	(0.56)
Fixed effects?			
Census tract	Yes	Yes	Yes
Year	Yes	Yes	Yes
Property type	Yes	Yes	Yes
R^2	0.43	0.97	0.98

Results from the regressions of capitalization rate (current earnings divided by sale price) and log of sale price on quake risk and property and transaction attributes. The regressors with reported coefficients are the average annual loss due to earthquake risk (obtained from AIR), the log earnings (second and third columns), indicators for whether a broker arranged the transaction and for whether the buyer was a broker, an indicator for corporate buyers, the 1990 property and personal crime risks (obtained from CAP Index), the age of the property, the log of buyer and seller distances from the property, an indicator for development projects and interactions between earthquake risk and the following variables: log of earnings and property age. In the fourth and fifth columns, the log of loan size is included as an additional control. All regressions include fixed effects for property type, year and census tract, with coefficients not reported for brevity. All regressions are estimated via ordinary least squares (OLS) with robust t-statistics reported in parentheses.

Table VII:
Effect of Northridge Earthquake on Commercial Real Estate Prices and Financing

Dependent variable	Cap rate	Bank Loan provided?	Log of bank assets	% Deposits in county
Sample	*All*	*All*	*L.A. County*	*L.A. County*
N	*12,444*	*32,618*	*3,989*	*3,596*
Quake Risk	1.5618	-2.7836	0.2840	0.3651
	(1.08)	(-2.96)	(0.16)	(1.38)
(Quake Risk) * Log (1+Days Post-quake)	0.1889	0.5732	0.1896	0.1204
	(0.58)	(2.57)	(0.38)	(1.77)
(Quake Risk) * (Year Post-quake)	-1.7086	-2.5987	0.3925	-0.4682
	(-1.03)	(-2.31)	(0.17)	(-1.53)
Log (1+Days Post-quake)	0.0205	0.0000	-0.1043	-0.0230
	(0.57)	(0.00)	(-1.09)	(-1.86)
PGA	0.0314	0.0114	-0.0304	0.0033
	(1.54)	(0.87)	(-1.22)	(0.88)
Log (Price)		-0.0090	0.8729	0.0460
		(-0.58)	(3.97)	(1.33)
Brokered	0.3767	0.5625	-0.0556	-0.0220
	(5.67)	(18.63)	(-0.48)	(-1.33)
Broker Buyer	0.1097	0.1501	-0.1380	0.0249
	(0.82)	(1.74)	(-0.54)	(0.87)
Corporate Buyer	0.2268	-0.1885	0.0178	0.0271
	(3.25)	(-5.61)	(0.13)	(1.43)
Property Crime	-0.0024	-0.0002	0.0010	0.0000
	(-1.64)	(-0.24)	(0.40)	(-0.06)
Personal Crime	0.0037	-0.0003	-0.0019	0.0001
	(2.88)	(-0.45)	(-0.79)	(0.19)
Log (Buyer Distance)	0.0423	-0.0909	-0.0160	0.0058
	(3.42)	(-12.70)	(-0.54)	(1.43)
Log (Seller Distance)	0.0433	-0.0004	0.0225	-0.0071
	(3.62)	(-0.06)	(0.98)	(-2.20)
Development	0.0938	0.0533	-0.3497	-0.0591
	(0.55)	(0.79)	(-1.05)	(-1.08)
Age	0.0053	-0.0017	0.0001	0.0003
	(3.21)	(-2.95)	(0.06)	(0.87)
Log (Loan Size)			-0.4557	-0.0699
			(-2.20)	(-2.09)
Fixed effects?				
Census tract	Yes	Yes	Yes	Yes
Property type	Yes	Yes	Yes	Yes
Year Fixed Effects?	Yes	Yes	Yes	Yes
Estimation method	*OLS*	*Logit*	*OLS*	*OLS*
R^2	0.43	0.19	0.37	0.35

Results from the regressions of capitalization (current earnings divided by sale price) rate, an indicator for whether a bank loan was provided, the log of the total assets of the bank extending the loan and the ratio of in-county deposits to total deposits for the bank extending the loan on quake risk, local shaking from the Northridge (1994) earthquake and property and transaction attributes. The data is drawn from the *COMPS* database. The regressors with reported coefficients are the average annual loss due to earthquake risk (obtained from AIR), the interaction of earthquake risk with the log of one plus the number of days following the Northridge quake on which the transaction took place (for transactions within one year of the quake), the interaction of earthquake risk with a dummy for the year following the Northridge quake, the log of one plus the number of days following the Northridge quake on which the transaction took place, the peak ground acceleration (PGA), a shaking intensity measure, of the Northridge earthquake at the property's location (provided by the USGS), the log of the sale price (excluded from the cap rate regression), indicators for whether a broker arranged the transaction and for whether the buyer was a broker, an indicator for corporate buyers, the 1990 property and personal crime risks (obtained from CAP Index), the age of the property, the log of buyer and seller distances from the property, an indicator for development projects, and, in the third and fourth columns, the log of loan amount. All regressions include fixed effects for property type, year and census tract, with coefficients not reported for brevity. The regressions are estimated via binary logistic regression (Logit) or ordinary least squares (OLS), as described, with robust t-statistics reported in parentheses. Reported R^2 for Logit specifications is McFadden's pseudo R^2.

Table VIII:
Effect of Northridge Earthquake on Transaction Volumes for Properties with Varying Quake Risks

Dependent variable	Quake risk	Quake risk	Quake risk
Sample	*All*	*Bank Loans*	*No Bank Loans*
N	*32,618*	*17,141*	*15,451*
Log (1+Days Post-quake)	0.0003	0.0008	0.0000
	(1.93)	(2.61)	(0.11)
PGA	0.0002	0.0002	0.0006
	(0.78)	(0.60)	(1.07)
Log (Price)	0.0000	0.0000	-0.0001
	(-0.20)	(-0.10)	(-0.64)
Brokered	0.0000	0.0003	-0.0003
	(-0.13)	(1.01)	(-0.94)
Broker Buyer	0.0000	0.0004	-0.0001
	(0.04)	(0.51)	(-0.12)
Corporate Buyer	0.0000	0.0000	-0.0002
	(-0.10)	(-0.05)	(-0.88)
Property Crime	0.0000	0.0000	0.0000
	(0.71)	(-0.44)	(0.82)
Personal Crime	0.0000	0.0000	0.0000
	(-0.73)	(0.32)	(-0.79)
Log (Buyer Distance)	0.0000	0.0000	0.0001
	(0.43)	(-0.45)	(1.26)
Log (Seller Distance)	0.0000	0.0000	0.0000
	(-0.22)	(-0.25)	(0.54)
Development	-0.0002	-0.0006	0.0006
	(-0.45)	(-1.33)	(1.38)
Age	0.0000	0.0000	0.0000
	(-0.48)	(-1.11)	(-0.40)
Fixed effects?			
Census tract	Yes	Yes	Yes
Year	Yes	Yes	Yes
Property type	Yes	Yes	Yes
Estimation method	*OLS*	*OLS*	*OLS*
R^2	0.99	0.99	0.99

Results from the regressions of the average annual loss due to earthquake risk on the log of one plus the number of days following the Northridge quake on which the transaction took place (for transactions within one year of the quake), local shaking from the Northridge earthquake, the log of the sale price, indicators for whether a broker arranged the transaction and for whether the buyer was a broker, an indicator for corporate buyers, the 1990 property and personal crime risks (obtained from CAP Index), the age of the property, the log of buyer and seller distances from the property, an indicator for development projects and property age. The data is drawn from the AIR, *COMPS* and USGS databases. All regressions include fixed effects for property type, year and census tract, with coefficients not reported for brevity. The regressions are estimated via ordinary least squares (OLS), with robust t-statistics reported in parentheses.