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Catastrophic Risks, a Catastrophic Event and Credit Markets

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ABSTRACT

We examine the effect of catastrophic risk on real estate financing and prices. Using unique micro-level data, we show that earthquake risk decreased commercial real estate loan provision by 22 percent in our California properties in the 1990's. In a study of the 1994 Northridge earthquake, we find that it reduced property prices and loan provision for no more than a year but caused an 11 percent long-term reduction in homeownership in Los Angeles county. Our results support Froot's (2001) finding of imperfections in catastrophe reinsurance markets, and we show this inefficiency leads to significant distortions in local credit markets.

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Catastrophic events can dramatically affect the well-being of people throughout entire regions. Episodes such as September 11, 2001 and the 2005 tsunami in Asia have highlighted the risks borne by individuals, particularly those with limited financial resources. Financial markets can help manage these risks by playing two crucial roles. First, markets provide a mechanism through which risk is allocated efficiently. Second, markets can supply the financing necessary for funding post-catastrophe reconstruction. Little is known, however, about how well financial markets perform these functions. Catastrophic risks are difficult to measure and catastrophic events are rare, making it challenging to find micro-level risk characteristics that can be linked to financial data.

In this paper, we provide an empirical analysis of how well financial markets perform these functions using unique data on catastrophic earthquake risk and commercial and residential property loan contracts and prices in the U.S. in the 1990s. 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 damage. Risk management theory suggests insurance is the most efficient mechanism for allocating the risks of large catastrophic events. However, Froot (2001) argues that the catastrophe insurance market fails to appropriately manage these risks as premiums appear high relative to expected losses and little catastrophe reinsurance is purchased by insurers. Consequently, capital markets may play a significant role in bearing catastrophic risks. We find that earthquake risk has a strong distortionary effect on local credit markets, which is consistent with the failure of traditional insurance markets for catastrophic risks. In the California commercial real estate loan markets we study, earthquake risk reduces the provision of bank financing by approximately 22 percent. However, the Northridge earthquake itself, a significant catastrophic event, had only a short-term effect on local prices and financing. The only long-term effect of the Northridge earthquake was a reduction in homeownership rates in Los Angeles county by 11 percent. This evidence suggests that earthquake risk is not allocated efficiently, but markets are relatively successful at financing post-event rebuilding.

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). Our focus, however, is on the effects of catastrophic risks and catastrophic events on local credit markets for commercial and residential real estate. We use a unique dataset of micro-level earthquake risks, provided by AIR Worldwide Corporation (AIR), and actual severity of ground

shaking, from the U.S. Geological Survey (USGS),¹ matched to micro-level financing and price information on commercial and residential properties (from Comps.com and the Home Mortgage Disclosure Act). Our empirical strategy relates property financing and pricing characteristics to earthquake risk and to actual shaking during the January, 1994 Northridge quake, controlling for property attributes and local characteristics. We include census tract or zip code fixed effects in all our analyses to difference out local unobservables at these levels. We are thus able to determine the within-neighborhood effects of earthquake risk and an earthquake event. This 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.

Froot (2001) contends that catastrophe insurance 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 argue that one plausible hypothesis for the reduced provision of bank loans in high quake risk areas is that banks require borrowers to obtain earthquake insurance in quake-prone regions and property buyers are unwilling to pay high earthquake insurance premiums, even if their refusal to do so causes them to forfeit mortgage financing. We also consider alternative mechanisms for sharing catastrophe risk. We provide two pieces of evidence that the secondary mortgage market reduces the impact of quake risk on financing. First, we find that quake risk has a relatively small effect on the financing of apartment loans, which are more frequently securitized than other commercial real estate loans. Second, we consider the differential treatment by banks of conforming and nonconforming residential mortgage applications. Conforming loans have loan amounts below a given threshold and may be purchased by the Federal National Mortgage Association (FNMA) and the Federal Home Loan Mortgage Corporation (FHLMC), the government-sponsored enterprises (GSEs). There is much greater securitization of conforming loans. We show that the approval rate for conforming residential mortgage applications is not dependent on quake risk, but nonconforming residential applications are significantly less likely to be approved in high quake risk areas. The GSEs are also more likely to purchase high quake risk loans. These findings provide additional evidence on the benefits of securitization and loan purchases by GSEs (Roll, 2003, Cotterman and Pearce, 1996).

In addition to its disruptive influence on real estate financing, we show that catastrophic risk

¹The peak ground acceleration (PGA) or maximum acceleration experienced at a specified location on the earth's surface during the course of an earthquake (USGS, 2004 - <http://eqhazmaps.usgs.gov>).

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 there is substantial variability in the manner in which quake risk is priced. In particular, we show that distant buyers, corporate buyers, and purchasers of large properties apply much greater discounts to properties with quake risk. From a risk perspective, this finding is hard to rationalize since local, non-corporate, and small buyers are likely less diversified and hence more exposed to the quake risk of an individual property. On the other hand, small buyers may not have access to geographically detailed quake risk data due to either a lack of information or because acquisition of such information involves paying some fixed cost and they are of insufficient scale.

While we find that quake risk is an important determinant of property financing and pricing, our analysis of the impact of an actual earthquake (Northridge, 1994) shows that real estate markets recovered from its effects quite quickly. Areas directly affected by the quake experienced lower commercial real estate prices and reduced financing in the year following the quake, but we find no effect beyond one year. In the residential market, we find little direct effect on the provision of mortgages from the Northridge quake. We do show, however, a significant increase one year after the event in the home improvement loan sizes demanded by residential property owners in the hardest-hit areas. The earthquake caused billions of dollars in property damage, and the costly rebuilding required financing. We show that banks are reluctant to extend home improvement loans in general, which suggests that wealthy individuals who do not require external financing may be the appropriate parties to undertake reconstruction after an earthquake. These wealthy individuals are spread throughout the local area, and are therefore likely to act as non-resident landlords after acquiring properties. Consistent with this story, we show that non-occupant buyers have much higher incomes. This argument suggests that an earthquake might lead to a decrease in homeownership, as wealthy non-occupant buyers purchase properties from less wealthy occupant sellers. Indeed, we find that areas that experienced greater shaking during the Northridge earthquake had lower homeownership rates in the subsequent six years.

Following the quake there was concern that heavily damaged areas would be abandoned and turn into virtual ghost towns (Bleich, 2003). We examine the long-term effect of the quake on local neighborhoods and find no long-term impact on home values, resident incomes or occupancy rates. The Northridge quake did not cause neighborhood devastation, but it did lead to a reduction in local homeownership and its attendant social benefits (Rohe, McCarthy and Van Zandt, 2000,

DiPasquale and Glaeser, 1999).

The remainder of the paper is organized as follows. Section I describes the commercial and residential real estate and earthquake data. Section II details the predictions we test. Section III investigates the effects of earthquake risk on real estate financing and prices. Section IV analyzes the impact of the Northridge quake on real estate markets and local neighborhoods. Section V concludes.

I. 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 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%. 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).

B. Loan application and origination data from the U.S. residential real estate market

Our data on the U.S. residential real estate market are drawn from the Home Mortgage Disclosure Act (HMDA) provided by the Federal Financial Institutions Examination Council. The Home Mortgage Disclosure Act (HMDA) was enacted by Congress in 1975 to monitor potentially discriminatory lending practices and to analyze geographic patterns of lending (Munnell, Tootell, Browne and McEneaney, 1996). All but the smallest banks, savings associations, credit unions and for-profit mortgage lending institutions must report HMDA data. We make use of all the 218,448 Loan Application Records for Los Angeles county in 1995.

Each record corresponds to a residential mortgage application and contains data on the identity of the lending institution, the census tract of the property, the purpose of the loan (1-4 family home purchase, home improvement or refinancing, or any purpose multifamily loan), the loan amount, the proposed occupancy status, income, race and gender of the applicant, the race and gender of any co-applicant, and the disposition of the application (loan originated, application approved but not accepted, application denied, application withdrawn by applicant or file closed for incompleteness). Summary statistics for the HMDA data are reported in Panel B of Table I.

C. Earthquake risk

AIR Worldwide Corporation (AIR) provides detailed data on the earthquake risks associated with our properties' locations. 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, characteristics. We use AIR's estimate of average annual loss as our measure of quake risk. AIR provides location-specific

matches for each of our COMPS properties at eight digit latitude and longitude coordinates. Since the HMDA residential property data are only available at the census tract level, we calculate the average quake risk across the COMPS properties in the tract, and then assign the average risk to all HMDA properties in the tract.

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 metres.²

Panel C 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.

D. The Northridge Earthquake

Our data and sample time 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, 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.³ 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. We average across all COMPS properties in a census tract to calculate the average PGA per tract, which we then assign to all

²This description of the AIR model is drawn from <http://www.air-worldwide.com>.

³The data may be found at <http://earthquake.usgs.gov/shakemap>.

HMDA properties in the tract. Summary statistics are given in Panel C of Table I.

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., who compute a crime score for a particular location by combining data from police reports, the FBI's *Uniform Crime Report* (UCR), client loss reports, and offender and victim surveys with geographic, economic, and population data. The crime risk estimates are property-specific for the COMPS data and vary within census tracts (see Garmaise and Moskowitz (2005) for further details). HMDA property crime risks are calculated by averaging across the crime risks of all COMPS properties in the same census tract. The census data come from the 1990 and 2000 U.S. censuses.

II. Predictions

We analyze the allocation of earthquake risk, its pricing, and the short- and long-term effects of a large earthquake (Northridge, 1994).

A. Is Earthquake Risk Optimally Allocated and Efficiently Priced?

Catastrophic risk is a natural candidate for insurance. The small private buyers who make up the vast majority of purchasers in our data set are poorly situated to bear the risk of a large earthquake. In a well-functioning earthquake insurance market, earthquake insurance should be almost universally purchased by the types of buyers in our sample. Since earthquake risk is commonly thought to be uncorrelated with overall financial wealth in the U.S., earthquake insurance should be offered on actuarially fair terms (Froot, 2001). The buyer chooses whether or not to purchase earthquake insurance, and his decision will affect the payoff of all claimants to the property, including any bank providing a mortgage. Although a well-diversified national bank supplying a mortgage may not benefit from the risk transfer aspect of earthquake insurance, the bank should be willing to subsidize the purchase of the insurance with, for example, lower interest rates, since the bank benefits from the insurance payments in the case of an earthquake if the borrower defaults. A local bank with substantial earthquake exposure may also derive risk benefits from the borrower's purchase of insurance. If insurance is offered on fair terms, therefore, it should be purchased by all buyers, even those seeking mortgages. If a building is insured, the bank's payoff will not be affected by an earthquake event. The presence of quake risk should not, therefore, discourage the provision

of finance if insurance markets are functioning properly. Our null hypothesis is that earthquake insurance markets are well-functioning.

Hypothesis 1A. *If quake risk is optimally allocated, then the probability a bank loan is extended is independent of a property's earthquake risk.*

Froot (2001), however, provides evidence that catastrophe reinsurance is dramatically overpriced, suggesting an alternative hypothesis that earthquake risk introduces distortions into the operation of local credit markets.

Our data does not provide information on the purchase of insurance by property buyers. If buyers fail to purchase insurance, however, (perhaps due to its excessive price), banks may be unwilling to provide a loan. A quake may cause severe damage that leads to a borrower's default, and banks may be very reluctant to take possession of such buildings. While earthquake risk will affect the expected cash flows from a property, and hence the terms under which loans are offered, if quake risk is being allocated optimally it should not affect whether or not a loan is provided, as argued above. If buyers refuse to purchase insurance and banks therefore refuse to lend, then all the quake risk will be borne by the buyer, which is surely not socially optimal. This analysis yields the following prediction.

Hypothesis 1B. *If quake risk is not optimally allocated, then the probability a bank loan is extended is decreasing in a property's earthquake risk.*

If, as Froot (2001) argues, catastrophic reinsurance is not properly priced, then under Hypothesis 1B other financing mechanisms may be useful in risk-sharing. We will consider, in particular, the role of the secondary mortgage market (i.e., securitization and/or purchase by the GSEs) in bearing earthquake risk.

Hypothesis 2. *The impact of quake risk on debt provision is smaller for loan types that are commonly sold into the secondary mortgage market.*

Even if catastrophic risk is efficiently allocated, however, quake risk should clearly reduce the value of the property. If insurance is not purchased, the owner faces the risk of property damage. If insurance is purchased, the premiums must be paid. For a given level of current earnings, the value of a property should decline in its earthquake risk.

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 $E[C_{t+1}|C_t] = C_t$. Each period t with probability p a fraction L of the property value V_t is destroyed by an earthquake. In the event of

an earthquake we presume that the property owner loses a fraction f of the current cash flows. We assume that earthquake risk is uncorrelated with economy-wide financial wealth (as argued by Froot, 2001) and that investors are well diversified.

We propose (and later confirm) that $V_t = kC_t$ for some constant k , where $\frac{1}{k}$ is the cap rate of the property. 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:

$$V_s = (1-p) \frac{E[C_{s+1} + V_{s+1}|C_s]}{1+r} + p \frac{E[(1-L)V_{s+1} + (1-f)C_{s+1}|C_s]}{1+r}. \quad (1)$$

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

$$kC_s = (1-p) \frac{(1+k)C_s}{1+r} + p \frac{((1-L)k + (1-f))C_s}{1+r},$$

which simplifies to

$$k(r + pL) = (1-p) + p(1-f).$$

This equation shows that k is a constant, so the valuation equation (1) is indeed satisfied by our proposed solution $V_t = kC_t$. The cap rate is then given by

$$\frac{1}{k} = \frac{r + pL}{(1-p) + p(1-f)}. \quad (2)$$

The average annual loss q is defined as $q = pL$. When $f = 0$ (all current cash flows are retained in the event of an earthquake), we have

$$\frac{1}{k} = r + q. \quad (3)$$

The average annual loss is sometimes described as the earthquake premium (Rüttener, Liechti and Eugster, 1999), and equation (3) makes precise the sense in which this description is accurate. If no current period cash flows are destroyed in the earthquake, then in the presence of earthquake risk the cap rate is simply increased by the average annual loss. If $f = L$ (current period cash flows are lost in the same proportion as overall value is destroyed), then

$$\frac{1}{k} = \frac{r + q}{1 - q}. \quad (4)$$

Since q will typically be quite small in most catastrophic risk settings, the distinction between (3) and (4) is likely to be minor in most applications. 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.

The derivative of the cap rate with respect to q is one under model (3) and slightly above one for any $f > 0$ in equation (2). If investors are not well diversified, and quake insurance is either not available or highly over-priced, the valuation effect of quake risk will be much larger (Hall and Murphy, 2000). We may therefore view one as a lower bound on the predicted coefficient from a regression of the cap rate on quake risk.

Hypothesis 3. *If quake risk is properly priced, then a property's cap rate is increasing in its earthquake risk. The derivative of the cap rate with respect to quake risk is at least one.*

If some market participants incorrectly incorporate quake risk into their valuations, price discrepancies may arise between different types of buyers. More sophisticated buyers likely account for quake risk correctly in their valuations, either because they understand how to price these risks or have the resources and information to do so. For these buyers, the elasticity of price to quake risk will be higher.

Hypothesis 4. *If quake risk is not properly priced by all investors, then the effect of quake risk on price is greater for more sophisticated buyers.*

B. What Is the Impact of an Actual Earthquake Event?

The first set of predictions pertain to the allocation of catastrophe event risk. We now consider the impact on financial markets of an actual catastrophic event, namely the 1994 Northridge, CA earthquake. There are several natural hypotheses about the effect of an actual earthquake. First, some properties experience actual physical damage from the event, and if there is heterogeneity in the impact of the earthquake across properties, which is a function of the severity of shaking affecting that property, then we have Hypothesis 5.

Hypothesis 5. *The cap rate of a property purchased after the Northridge earthquake is increasing in the severity of local shaking experienced during the quake.*

Second, the Northridge earthquake occurred on a previously unknown thrust, so quake risk assessments in the area rose after the event (Petak and Elahi, 2000). If these risks are not allocated efficiently (as Froot (2001) contends) then the Northridge earthquake may have also disrupted the provision of finance (Hypothesis 1). Banks may have also felt at an information disadvantage about the extent of property damage, which, along with general confusion at the time, may have disrupted the debt market.

Hypothesis 6. *The probability of a bank loan being extended after the Northridge earthquake is decreasing in the severity of local shaking experienced during the quake.*

In the aftermath of a destructive event like a large earthquake, there is a need for the infusion of capital for reconstruction. Much of this capital may be in the form of debt, but lenders will often insist on accompanying equity investments. Local residents will not necessarily have access to substantial investment capital, which suggests that real estate assets may be transferred to wealthy outsiders after an earthquake. These outsiders reside elsewhere and may act as non-resident landlords, which can reduce local homeownership rates.

Hypothesis 7. *Areas affected most severely by the Northridge earthquake experience drops in homeownership rates.*

After the earthquake, neighborhoods that experienced the greatest damage were labelled “ghost towns” by the city of Los Angeles Housing Department (Bleich, 2003). Roughly 7,500 housing units were vacated, and local crime increased. This exodus of residents may have been driven by declining home value or simply by a desire to leave an area that was newly revealed to be quake-prone. Heterogeneity in the severity of damage caused by the quake may therefore lead to variation in occupancy rates and home value changes across neighborhoods.

Hypothesis 8. *Areas affected most severely by the Northridge earthquake experience increased vacancy rates and drops in home values.*

In addition to the direct effects of the Northridge quake, press reports document that earthquake insurance rates across California rose dramatically in the aftermath of the Northridge earthquake (e.g., *Business Insurance*, July 4, 1994). 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. If perceived risks rise following a quake, then affected and unaffected areas will both experience price and lending distortions.

Hypothesis 9. *The effect of quake risk on a property’s cap rate increases after the Northridge earthquake, even in areas not damaged by the quake.*

Hypothesis 10. *The effect of quake risk on the probability that a loan is extended increases after the Northridge earthquake, even in areas not damaged by the quake.*

III. The Effects of Earthquake Risk on Financing and Prices

Using the micro-level earthquake risk and commercial and residential property loan data, we test the hypotheses outlined in Section II by examining the impact of earthquake risk on prices and financing.

A. Quake risk and commercial financing terms

Table II considers the effect of quake risk on the commercial real estate financing terms offered by banks, as detailed in the COMPS data set. 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). Banking market conditions are uniform within a census tract (Kwast, Starr-McCluer, and Wolken (1997)). Quake risk, however, need not be 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.⁴

Hypothesis 1A suggests that if earthquake risk can be insured at a fair price, then the risk should be transferred to insurers and there should be no effect on loan provision or loan terms. In our first test, however, we show the presence of quake risk results in a dramatic reduction in the provision of bank debt. In column 1 we regress a binary variable indicating whether or not the property purchase is financed with a loan on quake risk (i.e., average annual loss from the AIR data) and a set of control variables. The control variables include an indicator for whether the transaction is brokered, an indicator for whether the buyer is a broker himself, the log of the sale price, 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

⁴There are 334 zip codes that contain positive quake risk properties, and 131 zip codes (with 4,666 properties) that have within-zip-code variation in quake risk. The results in the paper are robust to using either zip code or census tract fixed effects.

are significantly less likely to receive bank financing (t -stat = -2.83). To evaluate the economic magnitude of the effect, consider the Los Angeles county observed frequency of financing of 58.46% and median quake risk of 0.2%. The point estimate on quake risk in the regression is -2.63 , implying a 13.06 percentage point reduction in the probability of loan provision to 45.40%.⁵ This reduction is 22.3% of the mean financing frequency. (The mean quake risk in Los Angeles county is 0.25%, which generates an even larger effect.) 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 . Examining all the California properties in the 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 financing, which is 22.2% of the mean. The size of these effects suggests that quake risk dramatically reduces the availability of bank finance in California, and in Los Angeles county in particular.

The substantial reduction in loan provision for high quake risk properties lends support to Froot’s (2001) contention that catastrophe, in particular earthquake, risk is not optimally allocated across market participants and may not be correctly priced. Under the null hypothesis that insurance markets function optimally (Hypothesis 1A), there should be no relation between earthquake risk and loan provision across insured borrowers. However, if catastrophe risk is overpriced and borrowers do not obtain insurance or catastrophe reinsurance markets function poorly, then capital markets may bear this risk (Hypothesis 1B). The evidence from the first column of Table II indicates that credit markets are indeed strongly affected by earthquake risk, consistent with Froot (2001) and Hypothesis 1B.

The effect of the reduction in loan provision is not uniform across properties. Column 2 of Table II reports results on the relation between loan provision and quake risk for various property types by including interactions between quake risk and the log of sale price and an indicator for development projects in the previous loan provision regression. The interaction between quake risk and log of price is significantly positive (t -stat = 6.51) and the interaction between quake risk and the development dummy is significantly negative (t -stat = -3.50), indicating that smaller buildings and development projects are especially negatively affected by quake risk. Since small, development projects are likely the most marginal loans made by banks, it is reasonable that quake risk affects

⁵The economic magnitude of a fixed effects logit is best considered in terms of its impact on the odds ratio. Loans are provided in 58.46% of Los Angeles county transactions, which gives an odds ratio of $\frac{0.5846}{1-0.5846} = 1.4073$. Since the estimated coefficient on quake risk is -2.6313 , a 0.2% increase in quake risk multiplies the odds ratio by $\exp(-2.6313 * .2) = 0.5908$, which yields an odds ratio of 0.8314, which is equivalent to a loan probability of 45.40%.

these properties most.

Quake risk should also have a smaller impact on bank financing for loan types that are commonly securitized (Hypothesis 2). Panel B of Table I shows that different property types are financed with debt with quite varying frequencies. Apartments, in particular, are especially likely to be financed with a bank loan due largely to the high level of securitization of apartment mortgages. Vandell (1998) shows that the securitization of apartment loans began earlier and was more extensive during our sample period relative to other commercial real estate loans. For example, 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. To test Hypothesis 2, we include an interaction term between quake risk and an apartment indicator in the previous loan provision regression. The interaction between quake risk and apartments is significantly positive (t -stat = 4.68), indicating that quake risk has less of a negative impact on the provision of loans for apartment buildings, which are more frequently securitized. Unfortunately, our data do not reveal whether the commercial loans in our sample are securitized or not. The residential loan data we analyze in Section III.B., however, permit a closer measure of the likelihood of securitization, and the results lend further support to Hypothesis 2.

In columns 4, 5, and 6 of Table II we analyze the effect of quake risk on the terms of the loan contract. Column 4 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, the debt maturity, an indicator for floating rate loans, an indicator for Small Business Administration-backed (SBA) loans, and bank fixed effects are included as regressors. We find that quake risk has a statistically insignificant effect on the interest rate (t -stat = 0.55). The coefficient is small in an economic sense as well since a 0.2% increase in quake risk is associated with only a 14 basis point increase in the annualized interest rate (the average annual rate in the sample is 8.3%). The magnitude of this effect contrasts sharply with the findings on loan provision. Column 5 of Table II examines the relation between loan size and quake risk. Conditional on a loan being extended, the size of the loan does not depend on quake risk either. In column 6 of Table II we examine the probability of multiple creditors providing financing on the property and its relation to quake risk. The specific risks associated with an earthquake event might be best managed by multiple creditors either for purposes of risk diversification or to commit to tough negotiation with the borrower in the event that the property is damaged (Bolton and Scharfstein (1996), Diamond (2004)). Regressing an

indicator for the presence of multiple lenders on quake risk (estimated by fixed effects logit) we find no significant relation between quake risk and the presence of multiple creditors.

The results in Table II show that quake risk results in much less bank financing, but conditional on the provision of a loan, quake risk appears to have almost no effect on its terms. One hypothesis consistent with these findings is that banks require that buyers purchase earthquake insurance as a precondition for a mortgage. Banks may be unwilling to risk the possibility that a quake will occur and leave them with damaged collateral; banks certainly have no special expertise in remedying quake damage and would likely fear being forced to liquidate damaged properties at low prices. If quake insurance is over-priced, insuring a small quake risk may be costly, but nonetheless worthwhile, because it enables the buyer to borrow from a bank. Buyers may elect not to insure large quake risks because the cost of this insurance is so high that it exceeds the value of both the insurance and the financing combined. Since properties with large quake risks are not insured, they are also not financed by banks. The lack of influence of quake risk on loan terms, under this theory, arises from the fact that once insurance has been purchased, quake risk is transferred to the insurer and is no longer a concern to the bank. Moreover, in unreported results, we also find that the interest rate, loan-to-value ratio, and probability of multiple creditors for loans on small properties and development projects are not differentially affected by quake risk, despite the fact that quake risk has an even greater impact on the loan provision of these properties. This result is consistent with catastrophe risk having little effect on loan terms despite its impact on loan provision. We also find that other attributes of the loan, such as maturity and floating/fixed rate status are not affected by quake risk.

The lack of significance on loan terms coupled with the very strong impact on loan provision are difficult to reconcile under alternative theories. For example, suppose as an alternative hypothesis, that different types of borrowers select properties (within a given census tract) with different risk characteristics. For instance, higher quality borrowers may avoid high quake risk properties. Hence, under this theory, our results on loan provision would simply be interpreted as reflecting the fact that higher quality borrowers are more likely to receive financing, and these borrowers purchase low quake risk properties. Quake risk, under this hypothesis, would have no causal effect on loan provision. Omitted variable problems of this type, however, cannot explain why loan terms are unaffected by quake risk. Any unobservable quality differences of borrowers that might be related to quake risk and financing provision, would almost certainly also be related to financing terms

the bank is willing to supply. Omitted variable problems of this type would predict greater loan provision *and* better loan terms. Since quake risk is only related to the probability of obtaining a loan, and is unrelated to any loan term, unobservable quality differences across borrowers cannot explain our findings. The same reasoning applies to unobserved heterogeneity in property structure quality or other attributes that are not captured by our quake risk measure.

The large reduction in financing of high quake risk properties suggests that the catastrophe insurance over-pricing documented by Froot (2001) has a large distortionary effect. 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)).⁶

B. Quake risk and commercial real estate pricing

Hypothesis 3 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 II. We report the results from this regression in column 1 of Table III. The results are inconclusive: the estimated coefficient of 1.26 is consistent with Hypothesis 3, but the t -statistic of 0.85 indicates that the null hypothesis of a coefficient of zero can also not be rejected. This test appears to have too little power to provide evidence either in favor of or opposed to Hypothesis 3. Other evidence in other studies supports Hypothesis 3: Nakagawa, Saito and Yamaga (2004, 2005) find that earthquake risk reduces rents and land prices in Tokyo.

Hypothesis 4 proposes that different investors may treat quake risk in varying ways. It may be, for example, that acquiring quake risk data at a level as fine as within a census tract is only feasible for sophisticated or large investors or requires the expenditure of some fixed cost. If investors have to pay a fixed cost to acquire the data, then one might expect them to do so only in larger deals or to do so if they are repeat buyers or agents in the market, such as brokers or developers.

To test this prediction, we first regress the log of the sale price on whether the deal is brokered, if the buyer is a broker, if the buyer is a corporation (as opposed to an individual), if the buyer is a developer, and the distance between the buyer (and seller) and the property. The set of control

⁶The overall rate of bank loan provision in California is 55.95%, which is actually slightly above the average rate in the whole sample. There are, however, macroeconomic, legal and regulatory reasons for why loan provision rates may differ across states (and indeed, the fraction of properties financed with bank loans varies quite dramatically across states in our data). Our census-tract fixed effects control for all such factors and allow us to isolate the effects of quake risk alone. The implication of our findings is that in the absence of quake risk, loan provision rates in California would be roughly 12.4 percentage points higher than what we observe in the data.

regressors used previously, including year and census tract fixed effects, is also employed. Column 2 of Table III shows that brokered deals are larger, and corporate buyers, developers, and distant buyers are much more likely to invest in large deals.

We then test Hypothesis 4 directly by regressing cap rate on quake risk and interactions between quake risk and indicators for buyers who are more than 25 miles from the property, corporate buyers, deals worth more than \$10 million, broker buyers, and brokered deals. The results are reported in column 3 of Table III. We find that the impact of quake risk on pricing is significantly greater for distant buyers and corporate buyers. These buyers are more likely to be sophisticated and are typically involved in larger deals. From a risk diversification standpoint, corporate buyers and distant buyers should be less averse to quake risk than individual and local buyers. Hence, this result cannot be explained by differences in risk bearing capacity across buyers. We also find that the coefficient on the interaction between quake risk and log of sale price is significant, though this variable is subject to bias arising from measurement error (since sale price appears in the denominator of the dependent variable). The interaction between quake risk and presence of a broker is also highly significant (t -stat = 4.33), indicating that quake risk reduces property values in brokered deals as well. Brokered deals may incorporate quake risk discounts more heavily either because clients who hire brokers are typically more sophisticated and larger (shown in column 2 of Table III) and are clearly willing to pay for professional services, including perhaps quake risk assessments, or perhaps because brokers are more aware of quake risks and incur the fixed costs of obtaining quake risk information through their role as repeated intermediaries. The coefficient on the interaction of quake risk and brokers who themselves are buyers is also positive, though it is statistically insignificant. The lack of significance on the broker buyer interaction term may stem from lack of power (brokers who are buyers comprise less than 2% of the transactions in our sample) or may indicate that it is the types of buyers who select brokers, not the brokers themselves, who pay more attention to quake risk.

C. Quake risk and the role of financial intermediaries

Do financial intermediaries ameliorate the distortions we find in the commercial real estate market? Since quake risk results in fewer loans, and this risk is diversifiable, one might expect larger and more distant banks to make a greater fraction of loans in high-quake-risk areas. If catastrophe insurance is very expensive, a large, well-diversified bank can essentially self-insure by making loans in a variety of areas.

In column 4 of Table III we display results from regressing the log of the assets of the bank making a loan on quake risk, the size of the loan, and the previous set of controls. We only include observations that include a loan and for which we can identify the lending bank in this regression. As the table indicates, banks making loans in high quake risk areas are not significantly larger in terms of asset size. In column 5 of Table III we regress the fraction of the issuing bank's deposits that are held within the same county as the property on quake risk. We find a marginally significant (t -stat = 1.65) *positive* coefficient on quake risk; local banks are more likely to make loans in high quake risk areas. This result suggests that considerations other than diversification of quake risk may also be important. It is plausible, for example, that extracting value from a property damaged by an earthquake (which will also have likely damaged most of the surrounding neighborhood) requires local knowledge and expertise. Large banks and especially distant banks may lack this expertise, making them inappropriate lenders to high quake risk properties, despite their well-diversified positions.

Property brokers also play an important role in the commercial real estate financing market, perhaps by intermediating between banks and buyers (Garmaise and Moskowitz, 2003). In column 6 of Table III we regress an indicator for brokered deals on quake risk and the usual set of controls (other than the broker variables). We do not find any significant relationship between quake risk and broker presence. There appears to be little evidence that financial intermediaries are ameliorating the negative impact of quake risk on local credit markets.

D. Quake risk and residential real estate financing

Evidence in Tables II and III suggests quake risk has a substantial disruptive effect on the financing of commercial properties. We now consider the impact of quake risk on the residential mortgage market by analyzing the 1995 HMDA data. We test Hypothesis 1 by regressing an indicator variable for whether a loan application is approved on quake risk, a set of applicant characteristics, and a group of census tract variables. The applicant characteristics are an indicator for whether the applicant intends to occupy the property, the log of the applicant's income, indicators for African-American, Hispanic and male applicants and an indicator for whether the loan application is guaranteed by the Federal Housing Administration (FHA), Veterans Administration (VA), Farm Service Agency (FSA) or Rural Housing Service (RHS). The census tract controls are the fraction of renters, the occupancy rate, the log of the median home value, the log of median income, the log of the median year built for housing units, the property crime risk and the personal crime risk.

All variables, except crime risk, are measured from the 1990 Census and the crime risks are the 1990 crime scores from Cap Index. The sample for the regression is the set of all loan applications made in support of 1-4 family unit home purchases in Los Angeles county in 1995. The HMDA data supply the census tract (but not the address) of the property that is being purchased. We therefore compute the quake risk variable at the census tract level by averaging over all the AIR quake risk scores for a given census tract and employ geographic fixed effects at the coarser zip code level. For each census tract, we find the zip code with which the tract has the greatest population overlap using the MABLE/Geocorr geographic correspondence engine (accessible at <http://plue.sedac.ciesin.org/plue/geocorr>). To properly account for the fact that the quake risk variable is measured at the census tract level, we estimate a linear probability model and compute standard errors that assume group-wise clustering at the census tract level.

Column 1 of Table IV shows that quake risk has no significant effect on the likelihood of loan application approval, indicating that the influence of quake risk is dramatically different in residential and commercial markets. This result, however, may be driven by the greater tendency for residential loans to be securitized. Hypothesis 2 states that loans that are commonly securitized should be less affected by quake risk. To test this conjecture and help determine the source of this disparity, we examine the effect of quake risk on conforming versus non-conforming loan applications. Non-conforming loans are those that exceed the maximum loan limit above which the Federal National Mortgage Association (FNMA) and the Federal Home Loan Mortgage Corporation (FHLMC) will not purchase loans. FNMA and FHLMC purchase 14.7% of the originated home purchase loans in our data set. As government-sponsored enterprises (GSEs), they are also subject to political pressures (Kane, 1999), that may induce them to purchase loans of homes subject to quake risk for non-economic reasons. (The government-owned corporation Government National Mortgage Association (GNMA) and the GSE Federal Agricultural Mortgage Corporation (FAMC) are subject to similar influences.) Loan approval decisions for loans above the conforming limit should not be subject to these considerations. In 1995, the conforming loan limit for 4-family units was \$390,400. We are not able to precisely determine the number of units, so we use the 4-family limit to assign non-conforming status since any 1-4 family unit property loan above this level is certainly non-conforming. In addition to directly purchasing conforming loans, FNMA and FHLMC facilitate a liquid market for the purchase of conforming loans by other financial institutions (Roll, 2003). In our data set, for example, 61.1% of the loans below \$390,000 are sold in the secondary

market, while only 30.2% of the loans above \$391,000 are sold. (Loan amounts are rounded to the nearest \$1,000.)

In column 2 of Table IV, we report the results from the loan approval regression for non-conforming loans only. We find a negative and significant coefficient on quake risk (t -stat = -2.20), consistent with the result for commercial real estate loans. Non-conforming residential loan applications are less likely to be approved in the presence of quake risk. A 0.2% increase in quake risk is associated with a 6.7 percentage point lower probability of loan approval for non-conforming loans. This evidence supports Hypothesis 2 that mortgages that are commonly securitized are less affected by quake risk and is consistent with the results we find for commercial loans, which are also less likely to be securitized.

We next analyze whether quake risk affects the terms of loans that banks extend. We regress the log of loan size for all originated home purchase loans on quake risk in column 3 of Table IV, and find that quake risk has no effect on loan size, even for non-conforming loans that are less likely to be securitized. These results are consistent with those for commercial properties: quake risk affects loan provision and not loan terms.

Given the large risks posed by an earthquake, it is natural to consider whether government-backed insurance is more frequently provided in earthquake-prone areas. We regress an indicator for the provision of insurance by the FHA, VA, FSA or RHS on quake risk (and the standard controls) and find that properties in high quake risk areas are significantly (t -stat = 1.78) more likely to have insurance. A 0.2% increase in quake risk is associated with a 3.0 percentage point increase in the probability that insurance is provided. Only 20.8% of home purchase loans are insured, so this effect represents a 14.3% increase in the likelihood of insurance.

Finally, we analyze the impact of the GSEs and GNMA on the securitization of loans with high quake risk. We regress an indicator for whether an originated loan was purchased by FNMA, FHLMC, GNMA or FAMC on quake risk and the previous controls. Column 5 of Table IV shows a positive and significant coefficient on quake risk that translates into a 3.0 percentage point increase in the probability that a loan is purchased by a GSE for a 0.2% increase in quake risk. Since 34.8% of loans are purchased by GSEs, this effect represents an 8.6% increase in the probability of a GSE purchase.

The 3.0 percentage point increase in GSE purchases suggests that direct purchase of high quake risk conforming loans by GSEs cannot by itself explain the entire 6.7 percentage point difference

between approval rates for conforming and non-conforming loans in earthquake-prone areas. It is likely that the ease of securitization for conforming loans also reduces the impact of localized quake risk on conforming loan approvals, since census-tract level geographic details are not usually provided to mortgage-backed securities buyers. Typically, coarser state-level information on the mortgage originator's location is given (Glaeser and Kallal, 1997, Downing, Jaffee and Wallace , 2005). Our finding that quake risk can have very strong effects on real estate financing even within a census tract raises obvious questions about possible asymmetric information problems faced by purchasers of mortgage-backed investments.

IV. The Effects 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.

A. The impact of Northridge on the commercial market

We first consider the effect of the earthquake on local cap rates. Earnings are reported for the previous year, so the effect of the Northridge quake on cap rates will largely reflect its effect on prices. We test Hypothesis 5 that cap rates rise (i.e., prices fall) by the greatest amount in areas experiencing the most severe shaking during the quake. We also test Hypothesis 9 that the price discount associated with quake risk increases after the Northridge quake. We regress cap rates on the peak ground acceleration (PGA), a measure of quake intensity, the quake risk of the property, and interactions between both PGA and quake risk and six month time dummies for each of the three half-year periods following the Northridge earthquake. The standard controls, including year, property type, and census tract fixed effects, along with dummies for the first and third six month period following the quake, are also included in the regression. The PGA measure captures the direct shaking effect of the Northridge earthquake, while the quake risk variable measures a property's susceptibility to future earthquake damage, irrespective of whether it was affected by the January, 1994 quake.

We report the results in the first column of Table V. We find that prices dropped significantly (t -stat = 2.54) in the portions of census tracts most affected by the Northridge quake in the immediate 6 months after the event. The mean PGA caused by the quake for the Los Angeles county properties in our data set is 26.78, which translates into an increase in the average cap rate

of 0.66 during the first 6 months post-quake period. Since the mean cap rate is 10.03, this result implies that the Northridge quake reduced prices by approximately 6.6% across Los Angeles county in the immediate six months following the event. This price reduction reflects both direct property destruction, indirect effects due to damage to neighboring buildings and any possible psychological aversion to buying properties in an area that recently received a large shock. The negative and significant coefficient on the interaction between quake risk and the dummy for the first six months after the quake, along with the positive coefficient on the level of quake risk, indicate that during the sixth months after January 17, 1994, controlling for the effects of the Northridge earthquake, overall quake risk had no impact on property pricing (the p -value that the sum of these coefficients is zero is 0.55). Buyers likely focused during this time on the impact of the Northridge quake itself, rather than on future unrelated earthquakes. There are no significant price effects in the 6-18 month period following the earthquake. We have little data from Los Angeles county following that period, but it seems unlikely that effects manifested themselves after 18 months. Our results are broadly consistent with Bleich (2003), who finds a 1-2 year effect of the Northridge quake on prices.

Hypothesis 6 states that the probability of bank financing decreases with PGA in the aftermath of the Northridge quake and Hypothesis 10 argues that the negative effect of quake risk on financing increases after the quake. We test these predictions by regressing the probability of financing on PGA, quake risk, and their interactions with six month time dummies following the Northridge quake. The results are reported in the second column of Table V. In support of Hypothesis 6, we find that PGA reduces the probability of a loan in the period 6-12 months after Northridge, though this effect appears to be transitory.

Quake risk, which has a strong statistically negative effect on the provision of bank finance in general, has a *less* negative impact on loan provision in the 6-12 month period after the Northridge quake, as indicated by the positive interactions with quake risk. This evidence is counter to Hypothesis 10. One possible reason for this finding is that many more buyers bought quake insurance following the Northridge quake (the California Department of Insurance (2003) reports that overall commercial quake insurance coverage increased in both Los Angeles and San Francisco in 1994 and 1995) despite the fact that quake insurance premiums rose dramatically during this period.⁷ If more borrowers purchased quake insurance in the aftermath of Northridge, then these

⁷See, for example, *Business Insurance*, Dec 26, 1994.Vol.28, Iss. 53; pg. 20. and *The San Francisco Chronicle*, February 18, 1995, Pg. D6.

results are consistent with our conjecture that banks tie the extension of a loan to the buyer's purchasing insurance. Hence, banks provided relatively more loans to high quake risk properties after the event because increased demand for insurance offset any fall in supply. Both the price and financing results show that the effects of the Northridge quake lasted no longer than one year.

We also examine the effects of the Northridge quake on the types of banks making loans to high quake risk properties. We regress the log of bank assets and the fraction of in-county deposits on PGA, quake risk, interactions between both PGA and quake risk and six month time dummies for each of the three half-year periods following the Northridge quake, and the usual controls. We find that the January, 1994 quake had no statistically significant effect either on the size of banks making loans (column 3) or the fraction of in-county deposits (column 4).

B. The impact of Northridge on the residential market

The results in Table V suggest that the price and financing effects of the Northridge earthquake on local commercial real estate markets were short-lived. The extensive damage caused by the quake, however, led to a dramatic increase in construction activity near the epicenter (Ong et al., 2003). Since this construction is typically financed with credit, the Northridge earthquake generated a positive shock to local demand for finance. Even in a smoothly functioning loan market, significant information and agency issues arise in the financing of home improvements and repairs. For example, the bank may not know whether the improvement will sufficiently enhance the home value, and may be concerned that a loan designed for purposes of repair will be diverted to other uses. In our data, the proportion of successful home improvement loan applications is only 49.9%, compared to 63.7% for home purchase loan applications, consistent with home improvement loans being riskier.

These arguments suggest that rebuilding after a quake may be most efficiently performed by those with large personal wealth who can undertake the repairs without resorting to loans. Wealthy individuals are likely to be scattered throughout the city, so one might expect an increase in non-local ownership after an earthquake. As suggested by Hypothesis 7, this shift in ownership may lead to decreased homeownership in areas most affected by the quake.

To examine this idea, we first use the 1995 HMDA data to test whether there was an increased demand for finance in the areas most affected by the Northridge quake. We consider the log of the ratio of loan size to applicant income for all originated home improvement loans. We regress this measure on PGA during the Northridge quake, quake risk and the full set of applicant characteristics

and census tract attributes employed in the regressions described in Table IV. We also include zip code level fixed effects to compare census tracts within a given zip code. As shown in column 1 of Table VI, the log of the loan amount to applicant income ratio is significantly (t -stat = 3.04) higher in census tracts that experienced greater shaking (PGA) during the Northridge quake. The economic magnitude of this effect is large: the 26.78 average PGA caused by the quake across our Los Angeles county properties is associated with a 25.3% increase in the the log of the ratio of loan amount to applicant income relative to the mean. This result indicates that there was a strong increase in demand for finance for home improvement, relative to applicant incomes. It is difficult to argue that the larger loan sizes in high PGA areas were driven by a supply shock that caused banks to want to lend greater amounts to those areas.

Since home improvement loans are difficult to obtain, wealthier buyers who can finance rebuilding internally may be better suited for reconstructing damaged homes. We argue that non-occupant buyers may be wealthier on average, since they include property owners with large real asset portfolios. To test this conjecture, we regress the log of applicant income on the full set of applicant and census tract attributes. We do not, of course, interpret the coefficients in this regression causally, rather they provide information on partial correlations. As reported in column 2 of Table VI, the coefficient on non-occupancy status is very highly and positively significant (t -stat = 27.10), indicating that non-occupants have higher incomes.

We also consider whether non-occupants receive larger home improvement loans than occupant buyers. For the sample of originated home improvement loans, we regress the log of the loan amount on non-occupant status and the set of controls. Column 3 of Table VI reports a significantly positive (t -stat = 4.55) coefficient on non-occupant buyers. It is interesting to contrast this result with the finding in the third column of Table IV that non-occupants receive substantially smaller home purchase loans. It is plausible that since non-occupants are generally wealthier, they may have a higher borrowing capacity but may typically need to borrow less. Thus, home purchase loans to non-occupants may be smaller because they have a smaller demand for such loans, while home improvement loans are larger because the bank is willing to supply them with bigger loans.

C. The impact of Northridge on local neighborhoods

The increased demand for finance in the areas most affected by the Northridge quake and the strong financial resources of non-occupant buyers that we document in Table V suggest that there may have been a permanent change in the renter/owner composition of impacted neighborhoods,

as predicted by Hypothesis 7. To test this hypothesis, we make use of data from the 1990 and 2000 U.S. censuses. We assign to each property the fraction of renters, occupancy rate, median home value, median income and median year built of its census tract in both 1990 and 2000. We regress the year 2000 fraction of renters on PGA, quake risk, the property and personal crime risks from CAP Index, and the following 1990 census variables: fraction of renters, occupancy rate, log of median home value, log of median income and log of median year built. Since many variables are measured at the census tract level, we use zip code fixed effects to difference out local unobservables. Estimation is by OLS, with robust standard errors clustered at the census tract level. The regression results are given in column 1 of Table VII. We find a positive and significant (t -stat = 2.71) effect of PGA on the fraction of renters. The magnitude of this effect is large. The mean 26.78 PGA caused by the quake in Los Angeles county is associated with a 5.33 percentage point increase in the fraction of renters. Since the fraction of renters in the county in 2000 is 47.9%, our estimates indicate that the Northridge earthquake raised the rental fraction by approximately 11%.

In the aftermath of the Northridge quake, there was concern that the most deeply affected areas would become abandoned ghost towns (Bleich, 2003). Hypothesis 8 states that areas that experienced the greatest shaking from the Northridge quake later suffered from increased vacancy and decreased home values. To test this hypothesis, we regress the 2000 occupancy rate on PGA, quake risk, the 1990 census tract controls and zip code fixed effects. As shown in the second column of Table VII, we find that the severity of the Northridge quake (PGA) had no statistically significant effect on occupancy rates. We also regress the log of the 2000 median home value in the tract on the PGA and quake risk and similarly find no effect, as described in column 3. The PGA also has no significant effect on the 2000 log of median income (fourth column) or 2000 median year in which housing is built (fifth column). Hence, the Northridge quake had no long-lasting effect on occupancy rates, home values, median incomes or age of housing. These findings go against Hypothesis 8, and may be attributed to the efficacy of the city of Los Angeles rebuilding efforts or to the natural dynamism of the housing market in the face of a catastrophic event such as an earthquake (Loukaitou-Sideris and Kamel, 2004). More broadly, it appears that credit markets are able to absorb the adverse effects of catastrophic events in relatively short amounts of time. While the Northridge quake had no significant medium-term effect on home values or local income, it did lead to a dramatic decline in the fraction of homeowners in Los Angeles county.

V. Conclusion

We empirically analyze the effects of earthquake risks and an actual earthquake event (January, 1994 Northridge) on credit markets in commercial and residential real estate. We find that earthquake-prone properties are much less likely to be financed with bank debt, and we provide evidence that small, local, non-corporate buyers do not properly incorporate earthquake risk into their valuations. Loan types that are more frequently transferred into the secondary mortgage market, such as apartment loans and conforming residential loans, are less affected by quake risk. The Northridge earthquake led to a one-year reduction in loan provision and local prices, but affected neighborhoods experienced no long-term consequences, except for a significant and lasting reduction in homeownership.

Our results suggest that during our sample period catastrophic risks were not optimally allocated, and this misallocation led to a substantial distortion in local loan markets. After the Northridge earthquake, however, credit markets were quickly able to supply the necessary resources to ameliorate most of the adverse effects of the catastrophe. Exposure to catastrophic risks, both natural and unnatural, continues to grow due to population shifts to at-risk areas 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.

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Table I: Summary Statistics of Commercial and Residential Real Estate Transactions, Quake Risk and the Effects of the Northridge (1994) Earthquake

| 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 HMDA loan applications and originations | | | |
|---|---------|---------|--------------------|
| | Mean | Median | Standard deviation |
| Loan amount (\$US) - all applications | 151,211 | 128,000 | 146,304 |
| Applicant income (\$US) - all applications | 81,517 | 58,000 | 127,602 |
| Loan amount (\$US) - originations | 152,298 | 130,000 | 131,990 |
| Applicant income (\$US) - originations | 83,713 | 60,000 | 136,794 |

| Panel C: 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 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 for loan amounts and applicant incomes for both loan applications and loan originations in the 1995 HMDA database. Panel C 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.

Table II: Earthquake Risk and Commercial Real Estate Financing Terms

| Dependent variable | Loan provided? | Loan provided? | Loan provided? | Interest rate | Leverage | Multiple lenders? |
|---------------------------------|---------------------|---------------------|---------------------|--------------------|--------------------|--------------------|
| <i># Obs.</i> | <i>32,618</i> | <i>32,618</i> | <i>32,618</i> | <i>3,970</i> | <i>11,583</i> | <i>23,454</i> |
| Quake risk | -2.6313 (-2.83) | -14.4745 (-7.06) | -15.3754 (-7.39) | 0.7082 (0.55) | -0.0276 (-0.32) | -0.0641 (-0.05) |
| Quake risk \times Log (Price) | | 0.8853 (6.51) | 0.9192 (6.68) | | | |
| Quake risk \times Development | | -2.3147 (-3.50) | -2.2637 (-3.39) | | | |
| Quake risk \times Apartment | | | 1.4143 (4.68) | | | |
| Brokered | 0.5620 (18.62) | 0.5580 (18.46) | 0.5530 (18.29) | -0.0620 (-0.92) | -0.0003 (-0.09) | -0.1170 (-2.17) |
| Broker buyer | 0.1520 (1.76) | 0.1487 (1.72) | 0.1366 (1.58) | -0.0676 (-0.58) | -0.0020 (-0.23) | 0.3837 (2.97) |
| Log (price) | -0.0094 (-0.61) | -0.0522 (-3.09) | -0.0503 (-2.99) | -0.0099 (-0.27) | | 0.1095 (3.61) |
| Corporate buyer | -0.1878 (-5.59) | -0.1925 (-5.72) | -0.1933 (-5.75) | 0.0457 (0.62) | 0.0158 (3.66) | -0.1435 (-2.20) |
| Property crime | -0.0002 (-0.27) | -0.0001 (-0.15) | -0.0001 (-0.18) | -0.0012 (-0.71) | 0.0001 (0.80) | -0.0022 (-1.94) |
| Personal crime | -0.0002 (-0.44) | -0.0003 (-0.57) | -0.0003 (-0.58) | 0.0013 (1.04) | 0.0000 (-0.41) | 0.0025 (2.38) |
| Age | -0.0017 (-2.93) | -0.0015 (-2.67) | -0.0013 (-2.43) | -0.0001 (-0.37) | 0.0001 (1.67) | 0.0026 (2.95) |
| Log (buyer distance) | -0.0908 (-12.70) | -0.0891 (-12.44) | -0.0887 (-12.40) | -0.0071 (-0.48) | -0.0022 (-2.28) | -0.0453 (-3.24) |
| Log (seller distance) | -0.0002 (-0.02) | 0.0005 (0.08) | 0.0010 (0.15) | 0.0272 (2.04) | 0.0010 (1.23) | -0.0649 (-5.39) |
| Development | 0.0541 (0.80) | 0.1729 (2.29) | 0.1673 (2.22) | 0.2757 (1.54) | 0.0142 (1.34) | 0.0307 (0.23) |
| Loan-to-value | | | | -0.4132 (-1.65) | | |
| Maturity | | | | -0.0112 (-4.18) | 0.0000 (-0.12) | |
| Floating | | | | -0.3120 (-4.62) | 0.0016 (0.67) | |
| SBA | | | | -0.2840 (-0.73) | 0.0661 (4.95) | |
| Geographic Fixed Effects | Tract | Tract | Tract | Tract | Tract | Tract |
| Bank Fixed Effects? | No | No | No | Yes | Yes | No |
| Year Fixed Effects? | Yes | Yes | Yes | Yes | Yes | Yes |
| Estimation Method | <i>Logit</i> | <i>Logit</i> | <i>Logit</i> | <i>OLS</i> | <i>OLS</i> | <i>Logit</i> |
| R^2 | 0.19 | 0.19 | 0.19 | 0.38 | 0.15 | 0.12 |

Results from the regressions of an indicator for whether a loan was provided (first through third columns), the interest rate on an extended loan (fourth column), the leverage (loan size divided by sale price) on an extended loan (fifth column) and an indicator for whether there were multiple lenders on an extended loan (sixth 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 (excluded from the leverage regression), 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, leverage, loan maturity in years, indicators for floating rate and Small-Business-Administration guaranteed loans, and interactions between earthquake risk and the following variables: log of sale price, an indicator for development projects and an indicator for apartment buildings. 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 III: Earthquake Risk and Commercial Real Estate Prices and Intermediation

| Dependent variable | Cap rate | Log of price | Cap rate | Log of bank assets | % Deposits in county | Brokered? |
|----------------------------------|--------------------|---------------------|--------------------|--------------------|----------------------|--------------------|
| # Obs. | 12,444 | 12,444 | 12,444 | 11,478 | 7,487 | 25,440 |
| Quake risk | 1.2609 (0.86) | -0.1040 (-0.27) | -1.1829 (-0.77) | 0.6033 (0.34) | 0.4360 (1.65) | 0.8716 (0.71) |
| Quake risk × Buyer distance > 25 | | | 2.2499 (4.71) | | | |
| Quake risk × Corporate buyer | | | 1.1083 (2.02) | | | |
| Quake risk × Price > \$10 mill. | | | 4.4150 (2.40) | | | |
| Quake risk × Broker buyer | | | 0.6130 (0.65) | | | |
| Quake risk × Brokered | | | 2.2366 (4.34) | | | |
| Brokered | 0.3786 (5.71) | 0.0416 (1.79) | 0.1490 (1.80) | 0.0777 (1.22) | -0.0218 (-1.74) | |
| Broker buyer | 0.1068 (0.80) | 0.0478 (1.11) | 0.0385 (0.20) | -0.1009 (-0.61) | 0.0038 (0.14) | |
| Log (price) | | | | 0.4168 (3.30) | -0.0010 (-0.05) | 0.0580 (3.21) |
| Corporate buyer | 0.2281 (3.27) | 0.5941 (21.78) | 0.1584 (1.95) | -0.0168 (-0.23) | -0.0063 (-0.47) | -0.2528 (-6.46) |
| Property crime | -0.0023 (-1.62) | 0.0002 (0.30) | -0.0022 (-1.52) | -0.0004 (-0.25) | 0.0000 (-0.12) | -0.0001 (-0.10) |
| Personal crime | 0.0037 (2.84) | -0.0011 (-2.23) | 0.0035 (2.67) | -0.0008 (-0.67) | 0.0001 (0.66) | -0.0005 (-0.70) |
| Age | 0.0053 (3.21) | -0.0114 (-22.63) | 0.0051 (3.07) | -0.0004 (-0.35) | 0.0000 (0.11) | -0.0004 (-0.51) |
| Log (buyer distance) | 0.0424 (3.42) | 0.1115 (19.96) | 0.1070 (5.19) | 0.0175 (1.06) | -0.0045 (-1.55) | 0.0079 (0.93) |
| Log (seller distance) | 0.0430 (3.59) | 0.0325 (6.98) | 0.0471 (3.92) | 0.0016 (0.12) | -0.0055 (-2.27) | 0.0693 (8.89) |
| Development | 0.0938 (0.55) | 0.1427 (1.99) | 0.1016 (0.60) | -0.3017 (-2.01) | -0.0051 (-0.15) | -0.0793 (-1.07) |
| Price > \$10 mill. | | | -0.7922 (-6.07) | | | |
| Buyer distance > 25 | | | -0.4735 (-4.40) | | | |
| Loan-to-value | | | | -0.0488 (-0.40) | -0.0265 (-1.28) | |
| Geographic Fixed Effects | Tract | Tract | Tract | Tract | Tract | Tract |
| Year Fixed Effects? | Yes | Yes | Yes | Yes | Yes | Yes |
| R^2 | 0.43 | 0.65 | 0.44 | 0.37 | 0.47 | 0.17 |

Results from the regressions of capitalization rate (current earnings divided by sale price), log of sale price, the log of the total assets of the bank extending the loan, the ratio of in-county deposits to total deposits for the bank extending the loan, and an indicator for whether a broker arranged the transaction 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, an indicator for development projects, an indicator for sales at a price above \$10 million, an indicator for buyer distance greater than 25 km and interactions between earthquake risk and the following variables: an indicator for buyer distance greater than 25 km, an indicator for corporate buyers, an indicator for sales at a price above \$10 million, an indicator for brokered transactions and an indicator for broker buyers. 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 that account for group-wise clustering at the census tract level.

Table IV: Earthquake Risk and the Financing of Residential Real Estate

| Sample: | All | Non-conforming | Originated | Originated | Conforming |
|-------------------------------|-----------------------|-----------------------|---------------------|---------------------|-------------------------|
| Dependent variable | Application approved? | Application approved? | Log of loan size | Insured? | Purchased by GSE, GNMA? |
| # Obs. | 96,563 | 4,735 | 61,000 | 61,000 | 58,594 |
| Quake risk | 0.0543 (0.96) | -0.3370 (-2.20) | 0.0429 (0.37) | 0.1487 (1.78) | 0.1496 (1.74) |
| Non-occupant buyer | -0.0101 (-1.24) | -0.0791 (-1.54) | -0.5021 (-34.18) | -0.0949 (-12.53) | -0.0779 (-7.18) |
| Log (applicant income) | 0.0343 (8.65) | 0.0968 (6.64) | 0.4578 (51.80) | -0.0883 (-15.21) | -0.0843 (-14.21) |
| Log (loan amount) | -0.0165 (-3.18) | -0.1718 (-5.57) | | 0.0674 (8.97) | -0.0266 (-2.90) |
| Applicant is African-American | -0.0913 (-11.62) | -0.0432 (-0.87) | 0.0461 (3.86) | 0.1303 (13.82) | -0.0410 (-4.45) |
| Applicant is Hispanic | -0.0145 (-2.59) | -0.0604 (-0.90) | 0.0286 (4.85) | 0.1287 (20.19) | -0.0385 (-6.19) |
| Applicant is male | 0.0110 (2.78) | 0.0036 (0.16) | 0.0529 (10.97) | 0.0282 (7.09) | -0.0013 (-0.26) |
| Insured | 0.1652 (26.18) | 1.0504 (5.79) | 0.0826 (9.81) | | -0.1781 (-25.68) |
| Fraction of renters | -0.0376 (-1.72) | -0.1906 (-1.76) | -0.1526 (-3.29) | 0.0396 (1.12) | -0.0459 (-1.38) |
| Occupancy rate | 0.0043 (0.05) | 0.0740 (0.11) | -0.5594 (-3.56) | 0.1909 (1.47) | 0.0036 (0.03) |
| Log (home value) | -0.0121 (-1.17) | -0.0475 (-0.51) | 0.1546 (5.45) | -0.0759 (-3.98) | -0.0488 (-3.20) |
| Log (income) | 0.0105 (0.63) | -0.0123 (-0.26) | 0.0957 (2.67) | -0.0343 (-1.72) | -0.0399 (-1.58) |
| Log (year built) | 0.0920 (0.15) | 4.3668 (1.22) | -5.8386 (-4.17) | 0.1403 (0.14) | 0.1889 (0.18) |
| Property crime | -0.0001 (-0.76) | -0.0003 (-0.33) | 0.0000 (0.40) | -0.0001 (-1.17) | -0.0001 (-1.32) |
| Personal crime | 0.0000 (-0.41) | 0.0006 (0.65) | -0.0001 (-0.73) | 0.0002 (2.34) | 0.0001 (1.75) |
| Geographic Fixed Effects | Zip Code | Zip Code | Zip Code | Zip Code | Zip Code |
| R^2 | 0.03 | 0.06 | 0.53 | 0.27 | 0.06 |

Results from the regressions of an indicator for whether a loan application is approved, the log of the loan size approved, an indicator for whether the loan application is insured by the Federal Housing Administration (FHA), Veterans Administration (VA), Farm Service Agency (FSA) or Rural Housing Service (RHS), and an indicator for whether an originated loan was purchased by the government-sponsored enterprises (GSEs) Federal National Mortgage Association (FNMA), Federal Home Loan Mortgage Corporation (FHLMC), or the government-owned corporation Government National Mortgage Association (GNMA) on quake risk and borrower and transaction attributes. The data is drawn from the 1995 HMDA database. The regressors with reported coefficients are the average annual loss in the property's census tract due to earthquake risk (obtained from AIR), an indicator for buyers who will not occupy the property, the log of the applicant income, the log of the loan amount, indicators for African-American, Hispanic and male applicants, an indicator for whether the loan application is insured by the FHA, VA, FSA or RHS (excluding the fourth column), and the following census-tract-level variables: the fraction of renters, the fraction of occupied properties, the log of median home value, the log of median income, the log of the median year in which a housing unit was built (from the 1990 U.S. census) and the 1990 property and personal crime risks (from CAP Index). All regressions include fixed effects for zip code and are estimated via ordinary least squares (OLS), with robust t -statistics reported in parentheses that account for group-wise clustering at the census tract level.

Table V: The Effect of the Northridge Earthquake on Commercial Real Estate Prices and Financing

| Dependent variable | Cap rate | Loan provided? | Log of bank assets | % Deposits in county |
|--------------------------------------|--------------------|---------------------|-----------------------|-------------------------|
| # Obs. | 12,444 | 32,618 | 11,478 | 7,487 |
| PGA | 0.0275 (1.36) | 0.0150 (1.13) | -0.0275 (-1.06) | 0.0037 (0.92) |
| Quake risk | 1.8374 (1.23) | -3.1195 (-3.25) | 0.2422 (0.13) | 0.4933 (1.79) |
| PGA × 0-6 months post-quake | 0.0248 (2.54) | -0.0061 (-1.08) | -0.0092 (-0.83) | 0.0010 (0.65) |
| Quake risk × 0-6 months post-quake | -2.8274 (-2.67) | 0.5952 (0.83) | 1.6107 (1.04) | -0.3028 (-1.39) |
| PGA × 6-12 months post-quake | 0.0032 (0.39) | -0.0149 (-2.64) | 0.0018 (0.17) | -0.0004 (-0.28) |
| Quake Risk × 6-12 months post-quake | -1.5646 (-1.54) | 2.1449 (3.07) | 0.3386 (0.24) | -0.0945 (-0.51) |
| PGA × 12-18 months post-quake | -0.0100 (-1.26) | 0.0012 (0.20) | 0.0135 (1.17) | -0.0011 (-0.75) |
| Quake Risk × 12-18 months post-quake | 0.3025 (0.29) | 0.1841 (0.25) | -0.3256 (-0.20) | 0.1636 (0.79) |
| Log (price) | | -0.0089 (-0.57) | 0.4218 (3.34) | -0.0013 (-0.06) |
| Brokered | 0.3718 (5.62) | 0.5623 (18.62) | 0.0856 (1.34) | -0.0217 (-1.73) |
| Broker buyer | 0.1020 (0.77) | 0.1527 (1.77) | -0.0946 (-0.57) | 0.0035 (0.13) |
| Corporate buyer | 0.2226 (3.19) | -0.1881 (-5.60) | -0.0180 (-0.25) | -0.0065 (-0.49) |
| Property crime | -0.0024 (-1.64) | -0.0002 (-0.26) | -0.0004 (-0.25) | 0.0000 (-0.19) |
| Personal crime | 0.0038 (2.88) | -0.0003 (-0.45) | -0.0009 (-0.68) | 0.0002 (0.73) |
| Log (buyer distance) | 0.0411 (3.32) | -0.0909 (-12.71) | 0.0179 (1.08) | -0.0046 (-1.62) |
| Log (seller distance) | 0.0434 (3.63) | -0.0003 (-0.05) | 0.0010 (0.08) | -0.0056 (-2.29) |
| Development | 0.0934 (0.55) | 0.0512 (0.76) | -0.3002 (-2.00) | -0.0047 (-0.14) |
| Age | 0.0053 (3.21) | -0.0017 (-2.94) | -0.0005 (-0.41) | 0.0000 (0.15) |
| Log (loan size) | | | -0.0523 (-0.43) | -0.0258 (-1.24) |
| Geographic Fixed Effects | Tract | Tract | Tract | Tract |
| Estimation Method | <i>OLS</i> | <i>Logit</i> | <i>OLS</i> | <i>OLS</i> |
| R^2 | 0.43 | 0.19 | 0.37 | 0.47 |

Results from the regressions of capitalization (current earnings divided by sale price) rate, an indicator for whether a 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 local shaking from the Northridge (1994) earthquake, quake risk and property and transaction attributes. The data is drawn from the COMPS database. The regressors with reported coefficients are the peak ground acceleration (PGA), a shaking intensity measure, of the Northridge earthquake at the property's location (provided by the USGS), the average annual loss due to earthquake risk (obtained from AIR), interactions between PGA and earthquake risk and time dummies for each of the three six-month periods following the Northridge earthquake, 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. Indicators for the first and third six-month period following the Northridge earthquake are included as additional controls. The regressions are estimated via binary logistic regression (Logit) or ordinary least squares (OLS), as described, with robust t -statistics reported in parentheses that assume group-wise clustering at the census tract level.

Table VI: The Effect of the Northridge Earthquake on the Residential Real Estate Market

| | Sample: Purpose: | Originated Loans Home Improvement | All Applications All | Originated Loans Home Improvement |
|-------------------------------|---------------------|--|----------------------------|--------------------------------------|
| Dependent variable | | Log of $\frac{\text{Loan size}}{\text{Applicant income}}$ | Log of Applicant income | Log of Loan size |
| # Obs. | | 11,487 | 204,885 | 11,487 |
| PGA | | 0.0104 (3.04) | -0.0023 (-1.99) | 0.0065 (2.02) |
| Quake risk | | -0.1958 (-0.58) | -0.1730 (-1.40) | -0.1124 (-0.35) |
| Non-occupant buyer | | -0.0001 (0.00) | 0.2919 (27.10) | 0.1858 (4.55) |
| Log (applicant income) | | | | 0.2775 (15.60) |
| Applicant is African-American | | 0.0771 (2.16) | -0.0462 (-6.28) | 0.0780 (2.41) |
| Applicant is Hispanic | | 0.1056 (4.25) | -0.1452 (-26.97) | -0.0037 (-0.16) |
| Applicant is Male | | -0.1882 (-7.93) | 0.2596 (56.09) | 0.0176 (0.88) |
| Insured | | -0.0480 (-2.58) | -0.0387 (-4.90) | 0.0331 (2.04) |
| Fraction of renters | | -0.1177 (-1.01) | -0.0695 (-1.36) | -0.1806 (-1.82) |
| Occupancy rate | | 0.3885 (0.75) | -1.0594 (-5.62) | -0.3207 (-0.82) |
| Log (home value) | | 0.0183 (0.28) | 0.1901 (4.07) | 0.1675 (3.17) |
| Log (tract median income) | | -0.2279 (-2.66) | 0.2641 (6.23) | -0.0846 (-1.07) |
| Log (year built) | | -4.8084 (-1.39) | -1.5453 (-1.04) | -4.2973 (-1.45) |
| Property crime | | -0.0002 (-0.57) | 0.0002 (2.27) | 0.0001 (0.16) |
| Personal crime | | 0.0006 (1.67) | -0.0003 (-2.86) | 0.0002 (0.66) |
| Geographic Fixed Effects | | Zip Code | Zip Code | Zip Code |
| R^2 | | 0.08 | 0.33 | 0.12 |

Results from the regressions of the log of the ratio of loan size to applicant income, the log of applicant income and the log of loan size on local shaking from the Northridge (1994) earthquake, quake risk and borrower and transaction attributes. The data is drawn from the 1995 HMDA database. The regressors with reported coefficients are the peak ground acceleration (PGA), a shaking intensity measure, of the Northridge earthquake in the property's census tract (provided by the USGS), the average annual loss in the property's census tract due to earthquake risk (obtained from AIR), an indicator for buyers who will not occupy the property, the log of the applicant income (in the third column only), indicators for African-American, Hispanic and male applicants, an indicator for whether the loan application is insured by the FHA, VA, FSA or RHS, and the following census-tract-level variables: the fraction of renters, the fraction of occupied properties, the log of median home value, the log of median income, the log of the median year in which a housing unit was built (from the 1990 U.S. census) and the 1990 property and personal crime risks (from CAP Index). All regressions include fixed effects for zip code, with coefficients not reported for brevity and are estimated via ordinary least squares (OLS), with robust t -statistics reported in parentheses that assume group-wise clustering at the census tract level.

Table VII: The Effect of the Northridge Earthquake on Local Neighborhoods

| Dependent variable | Fraction of renters in 2000 | Occupancy rate in 2000 | Log of Home value in 2000 | Log of Median income in 2000 | Log of Year built in 2000 |
|-----------------------------|-----------------------------------|---------------------------|---------------------------------|------------------------------------|---------------------------------|
| <i># Obs.</i> | 25,292 | 25,292 | 25,292 | 25,292 | 25,292 |
| PGA | 0.0020 (2.71) | 0.0004 (1.57) | -0.0005 (-0.19) | -0.0008 (-0.57) | 0.0000 (-0.68) |
| Quake risk | 0.0705 (1.23) | 0.0115 (0.83) | -0.1038 (-0.74) | -0.0632 (-0.69) | -0.0005 (-0.40) |
| Fraction of renters in 1990 | 0.5658 (15.84) | -0.0044 (-0.58) | 0.0223 (0.20) | -0.2328 (-3.77) | 0.0008 (0.88) |
| Occupancy rate - 1990 | -0.0875 (-0.80) | 0.1549 (4.27) | -0.4144 (-1.19) | -0.2651 (-1.30) | -0.0015 (-0.35) |
| Log (home value in 1990) | 0.0311 (2.13) | -0.0011 (-0.30) | 0.3066 (6.54) | 0.0816 (2.73) | 0.0005 (0.95) |
| Log (median income in 1990) | -0.0989 (-3.90) | 0.0194 (3.03) | 0.1958 (2.18) | 0.4554 (9.23) | 0.0000 (0.01) |
| Log (year built in 1990) | 0.7555 (0.75) | 0.3252 (1.33) | -9.2025 (-3.32) | -4.6415 (-2.44) | 0.6249 (17.51) |
| Property crime in 1990 | 0.0001 (2.08) | 0.0000 (1.78) | -0.0005 (-2.34) | -0.0004 (-3.01) | 0.0000 (1.37) |
| Personal crime in 1990 | 0.0000 (1.12) | 0.0000 (-2.23) | 0.0001 (0.65) | -0.0001 (-1.63) | 0.0000 (-1.24) |
| Geographic Fixed Effects | Zip Code | Zip Code | Zip Code | Zip Code | Zip Code |
| R^2 | 0.74 | 0.83 | 0.78 | 0.68 | 0.83 |

Results from the regressions of the following U.S. census 2000 census tract variables: the fraction of renters, the fraction of occupied properties, the log of median home value, the log of median income and the log of the median year in which a housing unit was built, on local shaking from the Northridge (1994) earthquake, quake risk and 1990 census tract variables. The data is drawn from the 1990 and 2000 U.S. censuses. The regressors with reported coefficients are the peak ground acceleration (PGA), a shaking intensity measure, of the Northridge earthquake in the property's census tract (provided by the USGS), the average annual loss in the property's census tract due to earthquake risk (obtained from AIR), the following U.S. census 1990 census-tract-level variables: the fraction of renters, the fraction of occupied properties, the log of median home value, the log of median income, the log of the median year in which a housing unit was built and the 1990 property and personal crime risks (from CAP Index). All regressions include fixed effects for zip code, with coefficients not reported for brevity and are estimated via ordinary least squares (OLS), with robust t -statistics reported in parentheses that account for group-wise clustering at the census tract level.