Business Losses, Transportation Damage, and the Northridge Earthquake

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ABSTRACT

The 1994 Northridge earthquake damaged four major freeways in the Los Angeles area. Southern California firms were surveyed to assess the role that these transportation disruptions played in business losses. Of the firms that reported any earthquake loss, 43% stated that some portion of their business loss was due to transportation damage. For the firms that attributed some loss to transportation damage, the average response was that 39% of their earthquake-related business losses were due to the disruptions in the transportation system. Overall, the survey results suggest that transportation damage played an important role in business losses following the earthquake.

INTRODUCTION

For years, earthquake research and recovery efforts have focused almost exclusively on the immediate property losses and injuries caused by the disaster. Scholars have only recently begun to estimate the economic losses due to business interruptions that follow a major earthquake. Those early estimates

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suggest that total economic losses add approximately 30% to damage estimates that are based only on the value of property damage (Gordon and Richardson 1995). This in turn suggests that economic disruptions are an important and yet poorly understood result of major earthquakes.

This paper summarizes a study of the link between business losses and the transportation damage that resulted from the Northridge earthquake. The results are from a survey of firms in the Los Angeles region. The survey asked firms to assess both their business losses due to the earthquake and how those losses were linked to the transportation disruptions. The results demonstrate that while transportation damage was not the only source of business losses, it was arguably as important as many other factors, including structural damage, property losses, and utility cut-offs. The implication is that the metropolitan transportation system plays an important role in business losses, and thus in economic recovery, following a major earthquake.

BACKGROUND

Prior Research

Research into economic losses caused by earthquakes can be grouped into three categories. Most studies of earthquake losses estimate direct property damage and do not consider broader economic losses (e.g., Dowrick and Rhoades 1992; EQE International 1994; National Research Council 1992, 77–82). More recently, "lifeline studies" have examined the link between regional economic performance and the major infrastructure systems that are vulnerable to damage during and following an earthquake (Applied Technology Council 1991; Chang and Taylor 1995). A third, and related, strand of research has estimated the value of the economic losses caused by various earthquakes (Gordon and Richardson 1995; Kroll et al 1991; Tierney 1995[1]).

[1] The study by Tierney, which is based on a survey of firms affected by the Northridge earthquake, is most similar to this paper. While Tierney's work was aimed at assessing business impacts, this paper gives more detailed information on the link between business impacts and transportation damage.

Both the lifeline studies and the research on regional economic losses share this study's focus on business impacts. However, most previous studies aimed at estimating the total value of any regional economic disruption caused by an earthquake. While important, this emphasis on regional economic aggregates obscures the detailed link between business losses and particular sources of damage, including transportation damage, which is the focus of this paper.

Transportation Damage Caused by the Northridge Earthquake

The Northridge earthquake damaged or destroyed bridges, ramps, roadways, and interchanges on Interstate 5 (I-5, the Golden State Freeway), Interstate 10 (I-10, the Santa Monica Freeway), State Route 14 (SR-14, the Antelope Valley Freeway), and State Route 118 (SR-118, the Simi Valley Freeway). See map and overview on pages iv–vi.

While all four freeway damage locations caused major disruptions to the ground transportation network, two are especially notable. Damage to the SR-14/I-5 interchange and damage further north on I-5 severed the highway link between the Santa Clarita Valley and the city of Los Angeles. The Santa Clarita Valley is a group of residential suburbs on the northern fringe of the Los Angeles urbanized area. With few alternative freeway routes into Los Angeles, the earthquake's highway damage left many commuters with little choice but to endure traffic delays that were initially greater than an hour during peak periods (Barton-Aschman and Associates 1994; Zamichow and Chu 1994).

The portion of the I-10 Freeway that was damaged is the major transportation artery for West Los Angeles, which is home to several of the region's largest employment centers (Giuliano and Small 1991). The substantial damage to this heavily traveled freeway was the focus of much policy discussion and media attention in the days immediately following the earthquake (Zamichow 1994).

Notably, the transportation damage from the Northridge earthquake was confined almost exclusively to the street and highway network. The major airports in the region and the ports of Los Angeles and Long Beach sustained no significant damage (Willson 1998). Similarly, both the freight and passenger rail systems in the region were almost untouched. For example, all Metrolink commuter rail lines in the region were in full service within three days after the earthquake[2] (Gardner Consulting Partners 1995). There was some damage to a crude oil pipeline, which required a shift to truck shipments, but that was minor in the context of the regional transportation system (Willson 1998). Overall, it is safe to assume that disruptions to goods movements and transit systems were primarily due to the damage to the street and road network, most importantly the highway damage described above.

While freeway repairs proceeded quickly, travel delays were substantial in the weeks and months following the earthquake. The California Department of Transportation estimated travel delays for all four major freeway damage locations. This was done with travel time runs along detour routes for each damaged corridor (Barton-Aschman and Associates 1994). The travel delays were measured relative to pre-earthquake travel times, and thus represent the incremental increase in travel times due to earthquake damage.[3] Most of the delay data are for weekday peak periods (6:00 a.m. to 9:00 a.m. and 3:00 p.m. to 6:00 p.m.), although there is some limited information about off-peak delays for specific corridors.

The peak-period delays for SR-14 and I-5 often exceeded an hour in the weeks immediately following the earthquake. By March 1994, once detours for both the SR-14 and I-5 damage had been implemented, peak-period delays along those corridors dropped to approximately 15 minutes. Off-peak travel time data showed no delay for the SR-14 corridor in March 1994 (Barton-Aschman and Associates 1994).

For the I-10 corridor in West Los Angeles, peak-period delays often exceeded 20 minutes, but fluctuated greatly during the first month following the earthquake. By the beginning of March 1994, delays on the I-10 corridor stabilized at 10 to 15 minutes until the freeway repair was completed on April 11, 1994. The limited data for off-peak travel along the I-10 corridor suggest that the off-peak delay was similar to the peak-period delay (Barton-Aschman and Associates 1994).

Along SR-118, peak-period delays initially ranged from 10 to 35 minutes. After a detour was implemented on local streets (on February 21, 1994), peak-period delays dropped to approximately five minutes. The available data show no travel time delay during the off-peak period for the SR-118 corridor (Barton-Aschman and Associates 1994).

Overall, the disruption to the highway network was substantial but short-lived for the corridors discussed above. Many damaged freeways were repaired within months of the Northridge earthquake, and travel delays (relative to pre-earthquake travel times) were only a few minutes for most corridors by March 1994. Given the large but transitory impact on the Los Angeles area highway system, how were businesses affected by the transportation damage?

STUDY DESIGN

To determine the impact of the freeway damage on business activity, 2,250 firms in the Los Angeles metropolitan area were surveyed. Those firms were asked questions about business losses, business losses attributed to transportation damage, the severity of a number of transportation and non-transportation impacts, and their response to the transportation damage. The survey instrument is described more completely in Boarnet (1995).

Geographic Areas

The 2,250 firms were drawn from three areas in the Los Angeles region, as shown on map 1. The area labeled "San Fernando Valley" includes the

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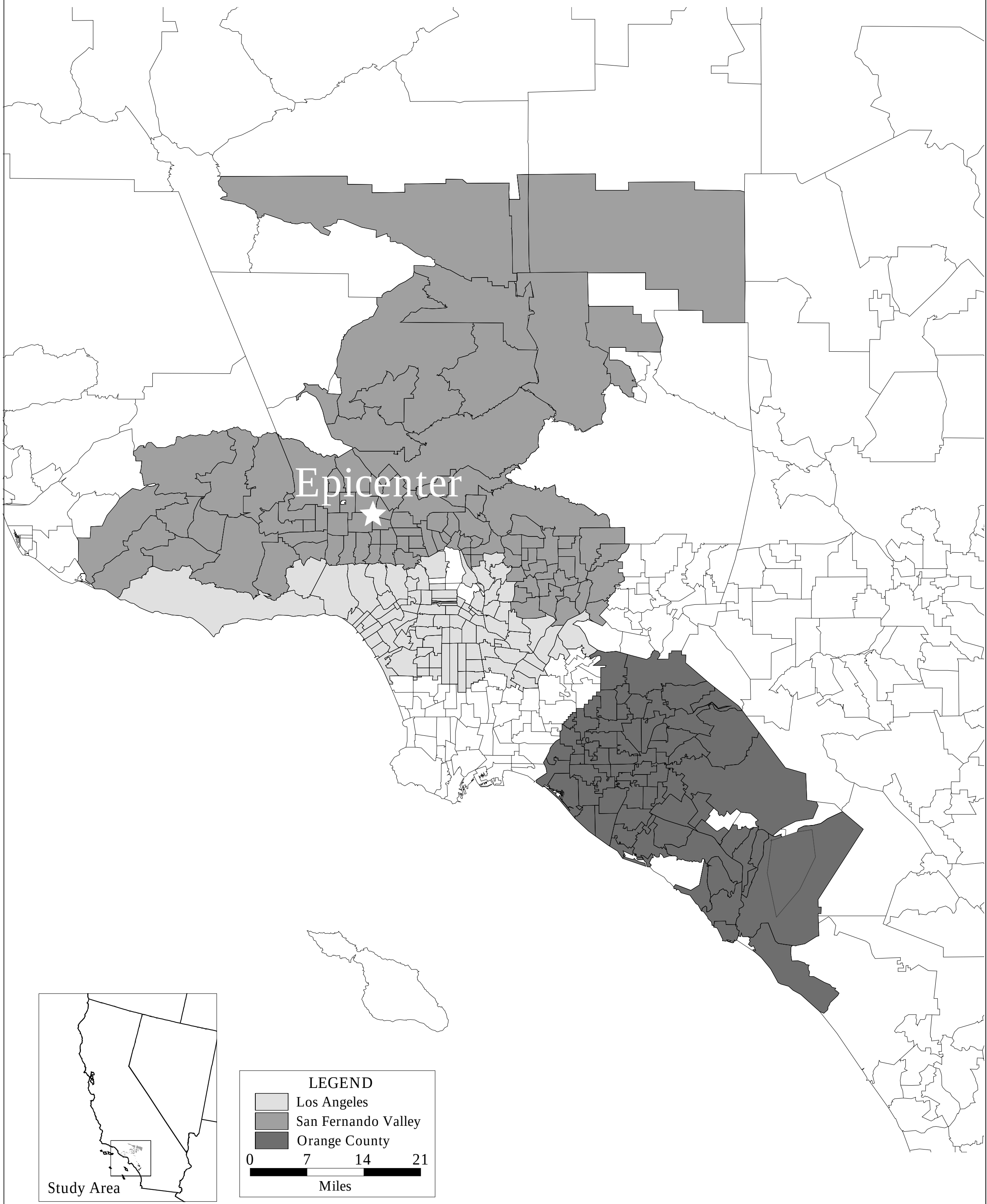
[2] If anything, mass transit service was improved in the immediate aftermath of the earthquake. The Metrolink commuter rail line was extended to Palmdale and Lancaster to help alleviate the bottleneck caused by the damage on I-5 and SR-14 (Barton-Aschman and Associates 1994). Bus systems added emergency service and new shuttle services were established to connect Metrolink or Amtrak stations with major employment centers (Ardekani and Shah 1995).

[3] Specifically, travel time delays were measured relative to assumed pre-earthquake travel speeds in all corridors of 55 mph, with the exception of an assumed pre-earthquake speed of 45 mph in the I-10 corridor (Barton-Aschman and Associates 1994). If anything, actual pre-earthquake peak period travel times might have been slower than the assumed speeds, such that the travel delays, if they are inaccurate, overestimate the magnitude of the earthquake's impact on the transportation system.

MAP 1 Geographic Areas



earthquake epicenter, all of the San Fernando Valley in northern Los Angeles, portions of the western San Gabriel Valley (e.g., Pasadena), the Santa Clarita Valley, and the high desert area in far northern Los Angeles County (e.g., Palmdale and Lancaster). "Los Angeles" includes downtown Los Angeles, Los Angeles International Airport, East Los Angeles, and Santa Monica. These two areas experienced the most intense earthquake damage.

For comparison, firms in Orange County were also sampled.[4] Orange County, while in the same consolidated metropolitan area as Los Angeles, was more than 50 miles from the epicenter and was much less affected by the earthquake. Orange County was included to provide a sample of firms that were in the same regional economy, but relatively distant from the epicenter. Note that, for purposes of this paper, the Orange County firms were not used as a counter-factual to attempt to answer what would have happened without an earthquake. The survey asked firms to estimate the extent of earthquake impacts, and the study design relied on the ability of firms to make those inferences. Orange County was included in the sample to provide greater variation in earthquake effects and in particular to allow an examination of how earthquake losses and transportation impacts varied with distance from both the epicenter and the highway damage.

Industry Groups

Manufacturing, retail, and wholesale firms were surveyed in all three study areas. Several factors were important in choosing these industry groups. Because the focus of the study was on the link between transportation damage and business losses, we chose industry groups based on an *a priori* assessment of how intensively those sectors relied on the ground transportation network for their day-to-day business activities. The retail and manufacturing sectors obviously depend on the transportation system to move goods and provide access to customers. Similarly, manufacturing firms depend on transportation access to ship their output.

In order to get a sufficiently large within-industry sample with a limited budget, some business sectors had to be excluded from the survey. Shipping firms were excluded because another research project (under the direction of Professor Richard Willson at California State Polytechnic University at Pomona) was already focusing on goods movement and shipping impacts due to the earthquake. Other industry groups, such as construction, services, and financial, insurance, and real estate (FIRE), were excluded because a large number of firms in those sectors might have experienced large losses or gains due to the earthquake, which might be unrelated to transportation. There was some concern that it would be difficult to discern the link between transportation and business losses for firms that either experienced net gains (as some construction firms might have) or for firms that experienced large losses not due to the highway damage (as might have been the case for firms linked to the insurance industry).

Overall, the goal of the project was not to sample all business sectors in the Los Angeles region, but to study three sectors that are important in their own right. Those three sectors (manufacturing, retail, and wholesale) account for approximately 40% of the firms in the Los Angeles metropolitan area.

Survey Methodology

The survey was mailed to 750 manufacturing firms, 750 retail firms, and 750 wholesale firms. The survey technique followed the methods described in Dillman (1978). Each group of firms was drawn randomly from the Dun and Bradstreet database of all firms for the Los Angeles City, San Fernando Valley, and Orange County study areas. The survey was mailed on October 19, 1994, non-

[4] More specifically, the study area boundaries were drawn as follows. The combined "San Fernando Valley" and "Los Angeles City" areas are bounded by the 105 Freeway on the south, the 605 Freeway on the east, Kern County on the north, and the Pacific Ocean and portions of Ventura County on the west. The study includes eastern Ventura County, because it is economically and geographically part of the San Fernando Valley area. Within the sampled regions—Los Angeles, Orange, and Ventura Counties—the three areas shown on map 1 are defined by zip codes as follows: the San Fernando Valley area includes firms with zip codes from 91000 through 91999 plus zip codes larger than 93000; the Los Angeles city area includes firms with zip codes between 90000 and 90999; and the Orange County area includes firms with zip codes between 92000 and 92999.

respondents were mailed a followup on November 15, 1994, and our research team began to contact nonrespondents by telephone in early December 1994. Telephone followup was completed in January 1995.

Some surveys were not able to be delivered to a firm due to incorrect address information. In all, 216 surveys, or 9.6% of the original population of 2,250 firms, were returned as undeliverable. Of the remaining 2,034 surveys that were delivered to a firm, 559 were completed and returned. This is a 27.48% response rate, which is not unusual for business surveys.

Selection Bias

Issues regarding selection bias typically can be addressed in three ways. First, it is common practice to consider the survey response rate, and to be more cautious when interpreting from surveys with low response rates. Second, one can examine whether the characteristics of survey respondents suggest some selection bias. Third, one can interpret the results in ways that allow for possible selection bias.

In terms of the first criterion, response rate, this research compares favorably with past surveys of firms. Tierney (1995) obtained a 23% response rate when surveying firms following the Northridge earthquake. More generally, several recent surveys of business populations have generated response rates similar to the 27% obtained in this study.[5] Having said that, surveys of firms bring special difficulties which, even in the best of circumstances, often result in lower response rates than for household surveys (Hansen et al 1983). For that reason, we carefully analyzed the most important source of bias for this research—whether response rates were influenced by the earthquake's effects.

Specifically, we examined whether the undeliverable and response rates within study area zip codes were related to the intensity of the ground shaking and the severity of the building damage caused by the earthquake.[6] Such a relationship might suggest that firms returned surveys based in part on their exposure to the earthquake's effects. Zip codes were grouped based on the four criteria listed below.[7]

1. *High Peak Ground Acceleration (PGA) Zip Codes:* All zip codes with average PGA greater than or equal to 0.5 G, where G is gravitational acceleration (32 feet/second^2). Out of the 263 zip codes in the study area, 13 met this criterion.

2. *High Modified Mercalli Intensity (MMI) Zip Codes:* All zip codes where ground shaking, measured by MMI, was greater than or equal to VIII. Thirty-six zip codes met that criterion.

3. *High Building Damage Zip Codes:* All zip codes where at least 25% of the building stock was inspected by local building authorities. Of the 263 zip codes, 16 met this criterion.

4. *Moderate Building Damage Zip Codes:* All zip codes where at least 10% of the building stock was inspected. Sixty-one zip codes met this criterion.

Given the four criteria outlined above, two-sample t-tests were used to examine whether response and undeliverable rates were significantly different in zip codes with severe ground shaking or building damage versus the balance of the study area. Those t-tests showed no evidence that undeliverable or completion rates varied based on the intensity of ground shaking or the geographic distribution of

[5] Kalafatis and Tsogas (1994) surveyed furniture manufacturers, and obtained response rates that varied from 20.3% to 52.4%. Of six different survey techniques tested, only one yielded a response rate larger than 40%, and two gave response rates lower than 30%. Childers and Ferrell (1979) surveyed members of the American Marketing Association and got response rates that ranged from 24% to 39%. Chawla and Nataraajam (1994), in a mail survey of southwestern business firms, obtained response rates that ranged from 29.5% to 37.5%.

[6] Recall that 216 surveys could not be delivered to the address in the Dun and Bradstreet database. It is conceivable that the undeliverable rate was influenced by the earthquake, e.g., if firms near the epicenter ceased operations due to earthquake damage. For that reason, the relationship between undeliverable rates and the intensity of ground shaking and building damage was examined.

[7] The data used to construct the zip code areas are from EQE International and Office of Emergency Services (1995, appendix C).

building damage.[8] (For the test results, see Boarnet 1995, Section 3, 31–41.) Overall, there is no evidence that firms either received or chose to return a survey based on their exposure to the earthquake's effects. This suggests that the most important source of bias, the earthquake itself, was likely not a major factor in determining which firms returned surveys.

The last point to consider is how the representativeness of the sample might influence the interpretation of the results. While exposure to severe earthquake effects does not appear to be an important source of bias, other characteristics did influence the response rates. Comparing businesses that returned surveys with the underlying population of 2,250 firms showed that retail firms were significantly underrepresented among respondents, manufacturing firms were significantly overrepresented, and firms in Ventura County were significantly overrepresented (Boarnet 1995).

The differences in response rates across industry groups suggest that inferences within an industry might be more reliable than inferences drawn from the entire sample. Yet the pattern of results (reported in the next section) is generally the same across the three industry groups, such that the differential response of the retail and manufacturing firms is not likely to crucially affect the inferences and conclusions reported in this paper. The response rate in Ventura County is an even smaller concern, since the overwhelming majority of firms in the population were from Los Angeles and Orange Counties.[9] The response rates in those two counties are representative of the proportion of firms in the underlying population.

RESULTS

Business Impacts

Table 1 gives information on the firms that stated that the earthquake caused them to lose money. (These are firms who responded "yes" to the question, "Did the Northridge earthquake cause your business to lose money?") Of the 559 firms that responded, 194 (35%) stated that the earthquake caused them to lose money. As table 1 shows, 25% of manufacturing firms reported earthquake business losses, 48% of retail firms said the earthquake caused losses, and 37% of wholesale firms reported business losses. The difference between the proportion of retail and manufacturing firms reporting losses is statistically significant at the 5% level. (The t-statistic is 4.28 with 59 degrees of freedom.) Similarly, the gap between the proportion of wholesale and the proportion of manufacturing firms that reported earthquake losses is also significant at the 5% level. (The t-statistic is 2.60 with 59 degrees of freedom.)

Of the 194 firms that reported earthquake losses, 170 estimated the total value of their losses.[10] The average self-reported loss was $85,026. The

[8] Only in one instance was there a statistically significant difference between areas. The undeliverable percentage was significantly *lower* in zip codes where MMI was greater than or equal to VIII. Yet, if undeliverables were due to earthquake impacts (either because firms moved or went out of business as a result of the earthquake), one would expect a *higher* undeliverable rate in areas with strong ground shaking.

[9] Of the 2,250 firms surveyed, 79 were in Ventura County.

[10] The survey asked firms to estimate "total business losses from the earthquake." Thus, the estimates likely represent total business losses at the time that the survey was administered (in fall 1994).

Table 1 Earthquake Business Losses, by Firm Type

Firm type	Number reporting earthquake-related business loss	Number completing survey	Percentage reporting earthquake-related business loss	Earthquake loss as percentage of 1993 sales[1]
Total	194	559	34.70	6.61
Manufacturing	59	232	25.43	4.45
Retail	61	127	48.03	7.26
Wholesale	74	200	37.00	8.06

[1] Reported only for the 194 firms that stated they had a business loss due to the earthquake. Data exclude three firms that reported earthquake losses that exceeded 1993 sales.

standard deviation of the loss was $225,602. The large standard deviation is due to a small number of outliers who reported very large losses.[11]

The last column of table 1 shows self-reported earthquake losses as a percentage of 1993 sales for those firms with 1993 sales data.[12] Manufacturing firms reported self-assessed losses averaging 4.45% of 1993 sales, retail firms reported losses averaging 7.26% of 1993 sales, and wholesale firms reported losses averaging 8.06% of 1993 sales. These inter-industry differences in losses as a percentage of sales are not statistically significant at the 5% level. (The two-sample test statistic for comparing losses as a percentage of sales for manufacturing and retail firms is 1.32. The two-sample test statistic for manufacturing and wholesale firms is 1.44. Both tests have 58 degrees of freedom.)

Manufacturing firms appear to be less affected than retail firms, at least in terms of the probability of reporting an earthquake loss.[13] It is not entirely clear why this is so. The manufacturing firms in the study are larger (on average) than the retail and wholesale firms, but probit regressions that predict the incidence of loss based on firm size (employees and sales) and firm type (retail and wholesale dummy variables) give insignificant coefficients for the size variables (Boarnet 1995, 43).

It is possible that the variations in the probability of an earthquake loss across firm types reflect a difference in earthquake vulnerability across firm types. Alternatively, it could be that the Northridge earthquake was centered in an area (the San Fernando Valley) that had a disproportionate number of retail and wholesale firms. Of the respondent firms with address information that could be matched to a geographic information system, 28% of the manufacturing firms were within a 20-mile radius of the epicenter, while 38% of retail respondents were within 20 miles of the epicenter, and 29% of wholesale respondents were within 20 miles of the epicenter. Thus, it might be that manufacturing firms reported a lower incidence of earthquake losses because those firms were further from the epicenter.

Business Losses and Transportation Damage

Firms that reported an earthquake-related business loss were asked whether they attributed any of that loss to the transportation damage resulting from the earthquake.[14] The responses are summarized in table 2.

Of the 194 firms that reported an earthquake business loss, 83 attributed some portion of that loss to transportation. Conditional on having an earthquake loss, the proportion of retail firms linking some portion of the loss to transportation (50.82%) is larger than the proportion of manufacturing firms attributing some loss to transportation damage (28.81%) at the 5% level. (The t-statistic for the difference between the sample proportions is 2.53 with 59 degrees of freedom.) Similarly, the proportion of wholesale firms that attributed some loss to transportation damage (47.39%) is larger than the proportion of manufacturing firms (28.81%), and the difference is again significant at the 5% level. (The t-statistic is 2.25 with 59 degrees of freedom.)

When focusing on transportation-related business losses, manufacturing firms appear to be less affected than retail or wholesale firms. This is similar to the pattern for overall business losses reported in table 1. Again, it is not clear whether manufacturing firms were less affected by the highway damage due to the nature of those firms, or

[11] Of the 559 firms that completed the survey, 58 (10%) stated that the earthquake caused business gains. The average self-reported gain, excluding two extreme outliers, was $52,234 with a standard deviation of $119,051.

[12] The Dun and Bradstreet database included information on 1993 sales revenue for most, but not all, firms.

[13] Because of the differential response rates across firm types discussed earlier, one might wonder whether this result is due to selection bias. While that is possible, note that the most obvious source of bias is not consistent with the results that were discussed above. Manufacturing firms were more likely to return surveys. If firms that were more affected by the earthquake (and thus more sensitized to the importance of the study) were more likely to return surveys, manufacturing firms would presumably have experienced more earthquake losses, rather than the lower incidence of loss reflected in the responses summarized in table 1.

[14] To not influence the results, firms were not informed of specific damage locations. The question asked whether firms could attribute any business losses to transportation damage from the earthquake. The survey specified that transportation damage included "road and highway damage, detours, closures, increased traffic due to road closures elsewhere, etc."

Table 2 Firms that Stated that Some Earthquake Loss was Due to Transportation, by Firm Type

Firm type	Number stating some loss due to transportation damage	Number reporting an earthquake-related loss	Percentage stating some loss due to transportation damage[1]	Average estimated percentage of total earthquake loss due to transportation damage
Total	83	194	42.78	38.96
Manufacturing	17	59	28.81	30.63
Retail	31	61	50.82	36.20
Wholesale	35	74	47.39	45.63

[1] Conditional on reporting an earthquake-related business loss.

whether retail and wholesale firms were more affected simply because more of those firms were closer to the epicenter and the highway damage.

Firms that attributed some loss to transportation damage were asked to estimate how much of their loss was due to this damage. The survey relied on firm self-assessments of transportation impacts. The questions did not identify specific transportation impacts or suggest how the damage might have been related to business losses. Instead, firms were left to their own judgment in assessing the highway damage and its impact on their business. This strategy had important advantages. Most notably, because the questionnaire did not ask detailed cost and revenue data, the survey could be completed quickly and easily.[15] Pre-tests had suggested that this was crucial in increasing the response rate.

Among firms that believed that transportation played a role in their business loss, the average response was that 39% of the total loss was due to transportation damage. This varied by firm type, and table 2 shows that retail and wholesale firms attributed a higher portion of their loss to transportation than did manufacturing firms. Yet the differences across industries in the fraction of loss attributed to transportation are not statistically significant at the 5% level.

The results in table 2 suggest that transportation played a reasonably important role in business losses from the Northridge earthquake. At least in the self-assessed data reported here, the fact that 43% of all firms with a loss attributed some loss to transportation, and that the average estimate for a transportation loss was 39% of all losses, both suggest that transportation damage was an important factor in earthquake business losses. Another way to illustrate this point is to compare firms' assessment of the effect of the transportation damage with their assessment of other earthquake effects.

Table 3 reports firm assessments of the severity of 10 different possible effects of the Northridge earthquake. Firms were asked to rate each effect on a scale from 1 to 5, with "1" meaning the effect was "no problem" and "5" meaning the effect was a "very severe problem." Note that the top four effects (or impacts) listed in table 3 are related to transportation. The other six impacts are arguably not related to transportation. Average scores for all

Table 3 Severity of Earthquake-Related Effects

	Average score on 1–5 scale[1]	Percentage of firms choosing 4 or 5
Customer access to business location	1.52	8.63
Employee access to business location	1.60	8.87
Shipping delays to business location	1.94	11.80
Shipping delays from business location	1.72	10.02
Building damage	1.38	4.48
Utility cut-offs	1.69	10.99
Higher prices/costs for goods and materials	1.32	3.96
Inventory loss or damage	1.56	9.31
Repair/cleanup (not included in building damage)	1.70	10.84
Seismic retrofit (not included in above)	1.21	2.34

[1] On a 1 to 5 scale, 1 indicates no problem and 5 indicates a very severe problem.

[15] Cost and revenue questions were asked, but those questions were left to the end of the survey. Many firms chose not to answer those questions. The information on firms' assessments of damages is thus much more reliable.

respondent firms are shown in table 3. Table 3 also shows the percentage of firms that gave each impact a severity rating of "4" or "5."

Table 3 illustrates two points. First, the earthquake impacts were moderate in the context of the entire region. Despite the publicity and large dollar value losses to property, the average severity ratings for all earthquake-related impacts were rated less than 2. Second, transportation appears to be as important as any other factor listed in table 3. The two earthquake effects with the highest average severity are "shipping delays to business location" and "shipping delays from business location." Overall, the severity ratings suggest an important role for transportation in the business losses that resulted from the earthquake. This is consistent with the information from the self-reported loss estimates reported earlier.

Table 4 gives severity ratings by geographic area, and table 5 gives severity ratings by firm type. The basic pattern is the same as that in table 3. Note that, in table 4, firms in the San Fernando Valley area gave all impacts higher ratings. This is expected given that the epicenter and many of the locations with the most damage were in the San Fernando Valley area. Also note that, in table 5, retail and wholesale firms generally gave higher severity rankings to the four transportation impacts than did manufacturing firms. This confirms the pattern from tables 1 and 2; retail and wholesale firms appear to be either more sensitive to the transportation disruptions or were more heavily affected by the highway damage caused by the Northridge earthquake.[16]

While the survey asked firms to assess what portion of their loss was due to transportation damage, the questionnaire did not ask firms to apportion transportation losses into a portion due to shipping versus other uses of the road system. Yet, tables 3 through 5 can give some insight into the role of shipping versus employee and customer access in transportation-related business losses. All categories of firms cited problems with employee and customer access, which, in terms of average severity, were almost as important as the shipping delays. The overall message is that transportation disruptions were not restricted to freight movement, but extended to other types of accessibility provided by the highway system.

[16] Severity rankings were also examined for only those firms that reported an earthquake loss, firms that reported a transportation-related business loss, firms in zip codes where PGA exceeded 0.5, firms in zip codes with MMI greater than or equal to VIII, firms in zip codes where at least 10% of the building stock was inspected, and firms in zip codes where at least 25% of the building stock was inspected. For all these groups, the severity ratings show the same general pattern in terms of the assessment of transportation impacts relative to the nontransportation impacts. Of course, severity rankings in the areas with intense ground shaking and large amounts of building damage were higher than for other areas. See Boarnet (1995) for details.

Table 4 Severity of Earthquake-Related Effects, by Geographic Area

	Average score			Percentage of firms with 4 or 5 score[1]		
Effect	Los Angeles City	Orange County	San Fernando Valley	Los Angeles City	Orange County	San Fernando Valley
Customer access to business location	1.56	1.20	1.72	7.69	2.72	14.61
Employee access to business location	1.68	1.24	1.84	7.77	3.38	14.27
Shipping delay to business location	1.91	1.68	2.19	10.53	4.76	19.10
Shipping delay from business location	1.71	1.28	2.10	7.73	3.45	18.08
Building damage	1.38	1.14	1.57	2.86	2.72	7.82
Utility cut-offs	1.69	1.16	2.11	11.00	3.40	17.13
Higher prices/costs for goods and materials	1.39	1.16	1.38	3.85	2.05	5.68
Inventory loss or damage	1.53	1.16	1.92	8.10	2.60	16.20
Repair/cleanup (not included in building damage)	1.67	1.18	2.18	8.10	2.74	20.67
Seismic retrofit (not included in above)	1.15	1.15	1.33	1.00	2.74	3.59

[1] On a 1 to 5 scale, 1 indicates no problem and 5 indicates a very severe problem.

Table 5 Severity of Earthquake-Related Effects, by Firm Type

	Average score			Percentage of firms with 4 or 5 score[1]		
Effect	Manufacturing	Retail	Wholesale	Manufacturing	Retail	Wholesale
Customer access to business location	1.35	1.73	1.58	5.91	12.71	9.23
Employee access to business location	1.48	1.67	1.69	5.88	9.48	11.92
Shipping delay to business location	1.82	2.09	1.99	9.87	13.56	12.95
Shipping delay from business location	1.66	1.57	1.88	9.55	7.76	11.92
Building damage	1.29	1.53	1.38	2.24	5.88	6.19
Utility cut-offs	1.62	1.79	1.70	8.48	15.25	11.28
Higher prices/costs for goods and materials	1.25	1.44	1.34	2.25	4.31	5.73
Inventory loss or damage	1.37	2.11	1.42	4.93	22.31	6.22
Repair/cleanup (not included in building damage)	1.58	2.29	1.49	6.28	27.12	6.19
Seismic retrofit (not included in above)	1.12	1.42	1.19	0.47	5.50	2.65

[1] On a 1 to 5 scale, 1 indicates no problem and 5 indicates a very severe problem.

Another way to get insight into this issue is to examine how firms both perceived and responded to changes in their employees' commutes. Table 6 summarizes firm responses to a question that asked whether ". . . some employees required longer commute times to get to work."[17] The responses are tabulated by geographic area in table 6.[18]

Close to 40% of the firms in both the San Fernando Valley and the Los Angeles City areas stated that their employees had longer commute times after the earthquake. When firms were asked to assess how quickly employee commutes returned to pre-earthquake conditions, the median response was one month for the entire sample. For firms in the San Fernando Valley area, the median assessment of how quickly employee commutes returned to normal was two months.

Table 7 shows the percentage of firms who used each of three possible policies to respond to their employees' commuting problems following the Northridge earthquake.[19] Neither ridesharing nor

Table 6 Firms that Stated that Their Employees had Longer Commutes, by Geographic Area

Geographic area	Number stating that employees had longer commutes	Number completing survey	Percentage with employees with longer commutes
Total	176	559	31.48
Los Angeles City	81	219	36.97
Orange County	19	149	12.75
San Fernando Valley	76	191	39.79

Table 7 Policies To Mitigate Disruptions to Employee Commuting, by Geographic Area (In percent)

Geographic area	Arranged ridesharing, vanpools, and carpools	Encourage use of public transportation	Allow changed work hours
Total	7.33	10.91	19.14
Los Angeles City	9.13	15.98	18.72
Orange County	3.36	3.36	10.07
San Fernando Valley	8.38	10.99	26.70

[17] Note that the focus here is on assessing how firms were affected by commuting disruptions. For that reason, it was appropriate to ask firms about their assessments of employee commutes.

[18] There were no statistically significant differences across industry groups in the proportion of firms stating that their employees had longer commutes.

[19] These are the firms that responded "yes" when asked: "During the time immediately following the earthquake, did your firm implement any of the following policies?" The three possible choices were "arrange ridesharing, vanpools, or carpools," "encourage employees to use public transportation," and "allow employees to change their work hours to avoid traffic." Firms were allowed to answer "yes" to any or all of the three policies.

public transportation were widely popular, and the incidence of both policies was lower than the percentage of firms that stated that their employees endured longer commutes. The most common policy was allowing employees to change their work hours. This was used by 19% of all respondent firms, and 27% of firms in the San Fernando Valley area.

Distance Decay and Transportation Losses

Common sense dictates that many earthquake impacts are most severe nearest the epicenter. While soil conditions, building quality and age, and other factors also influence earthquake damage, proximity to the epicenter is a key factor in earthquake impacts. Suarez-Villa and Walrod (1996) document that, for advanced electronics manufacturing firms in the Los Angeles area, those within five miles of the epicenter experienced the greatest disruption in terms of workdays lost due to the Northridge earthquake.

For the manufacturing, retail, and wholesale firms surveyed here, the probability of reporting an earthquake loss, the magnitude of the loss, the probability of reporting an earthquake-related business closure, and the probability of reporting building damage are all significantly explained by distance from the epicenter and severe ground shaking. (For results, see Boarnet 1995.) Given that, how do transportation-related business losses correspond to distance from the epicenter and the location of major freeway damage?

Table 8 gives probit regressions for the probability of reporting that some business losses were due to transportation damage, conditional on reporting any earthquake loss. Before discussing the regression results, note that the distance decay pattern for transportation damage (or any earthquake-related effect) might be nonlinear. Distance might only be an important predictor of severity close to the epicenter. This is especially important given the inclusion of Orange County firms, all of which are reasonably distant (over 40 miles) from the epicenter and somewhat unaffected by the earthquake.

For that reason, the effect of distance was modeled using a threshold. The regressions in table 8 include a variable that measures distance (in miles) from the epicenter, and the distance variable interacted with a dummy variable that equals 1 if the firm is within 20 miles of the epicenter. This allows the distance decay pattern to differ within and outside of a 20-mile threshold. The 20-mile threshold was chosen based on a visual examination of the distance decay pattern for lost workdays for the survey respondents. Threshold distances of 5 and 10 miles were also tested, and the results were never qualitatively different from those shown in table 8. Similarly, other nonlinear representations for the distance decay were examined, including

Table 8 Probit Regressions for Stating that Some Loss was Due to Transportation[1]

Independent variable	All firms	Manufacturing firms	Retail firms	Wholesale firms
Retail dummy	0.541 (0.264)			
Wholesale dummy	0.513 (0.251)			
Distance from epicenter	6.7×10^{-4} (7.1×10^{-3})	-7.6×10^{-3} (0.014)	–0.009 (0.015)	0.010 (0.010)
Distance* 20-mile dummy[2]	1.9×10^{-3} (1.7×10^{-2})	–0.034 (0.038)	8.5×10^{-4} (0.031)	0.017 (0.026)
Constant	–0.615 (0.274)	–0.288 (0.418)	0.125 (0.479)	–0.408 (0.368)
Number of observations	165	47	52	66
Log(L)	–109.34	–27.28	–35.76	–45.12

[1] Conditional on reporting an earthquake business loss. Standard errors are in parentheses.

[2] Distance from epicenter multiplied by a dummy variable that equals 1 if the firm is within 20 miles of the epicenter.

using distance and its square as independent variables, and again the results were qualitatively the same as in table 8.[20]

Note that no distance variable is statistically significant in table 8. This result holds whether all firms are pooled or for each firm type separately. The distance variables were also insignificant when the model in table 8 was estimated using both logit and ordinary least squares estimation. Robust standard errors were used for the least squares estimates to avoid heteroskedasticity problems, which are caused by estimating limited dependent variables models with least squares. The model in table 8 was also specified using straight-line distance from each of the four freeway damage locations, and again the distance variables were statistically insignificant.[21]

Unlike other earthquake-related effects, the incidence of transportation losses is not significantly related to distance from either the epicenter or the freeway damage. The dense transportation network in Los Angeles (and most other cities) provides travelers with different routes to get to the same location. Depending on a particular firm's needs, travel patterns, and location, the freeway damage may or may not have posed a serious problem. Factors such as how the transportation system is used and the availability of alternate routes might be poorly correlated with distance from both the epicenter and freeway damage. Overall, while it is sensible to expect most earthquake impacts to decay with distance, that same pattern does not appear for transportation losses. The complexity of the transportation system, and the interaction between any one firm's needs and the highway network, creates a pattern where the transportation-related losses are more geographically dispersed than for other earthquake effects.[22]

SUMMARY AND CONCLUSION

The evidence above suggests that the Northridge earthquake was a relatively moderate event, both in terms of the size of business losses relative to sales and in terms of the average severity ratings summarized in tables 3 through 5. Having said that, transportation damage appears to be roughly as important as any other source of loss, including structural damage and other lifeline disruptions. It is possible that retail and wholesale firms are more vulnerable to transportation losses compared with manufacturing firms, but this result could also be due to a higher proportion of retail (and to some extent wholesale) firms near the epicenter and the damaged highways.

Possibly the most important fact to come from this analysis is the lack of any relationship between distance from the transportation damage and business losses. While both common sense and experience suggest that earthquake impacts will be most severe near the epicenter, transportation-related business losses are an exception, at least in the case of the Northridge earthquake. Distance to a damaged freeway or the epicenter was not a good predictor of whether a firm experienced a transportation-related business loss. The incidence of loss depends not only on the spatial distribution of highway damage, but on how individual firms use the highway network. Firms that were distant from the highway damage but depended heavily on access through those corridors might have been more heavily affected than firms that were closer to the damage but relied less on those freeways. Future research might examine in more detail how dependence on the highway network varies across different types of firms, and how that creates variation in vulnerability to earthquake disruptions or other major transportation damage.

There are relatively few opportunities to observe transportation disruptions of the magnitude caused by the Northridge earthquake. The results

[20] The results are the same if Orange County firms are excluded from the analysis and if distance is represented linearly rather than with a threshold effect. Results are available upon request.

[21] Complete test results are available upon request.

[22] One might be tempted to test the distance decay relationship using travel time delays rather than distance from the epicenter or freeway damage. Yet, time delay captures only part of the complexity of the transportation system. A firm might be near a large bottleneck but relatively unaffected if they rarely use the congested transportation artery. Similarly, a firm that depends on shipping goods through a distant but congested damage location might be heavily affected by the freeway damage. Lacking more detailed information on how firms use the transportation system, it was not possible to incorporate the available travel delay data into a more sophisticated model of transportation-related business losses.

of this study demonstrate that manufacturing, retail, and wholesale businesses believed that transportation damage played an important role in their overall losses. This highlights the link between transportation systems and the functioning of the regional economy, and also emphasizes the role that transportation systems might play in economic recovery from major disasters. Future research might examine more closely how particular firms differ in their ability to adapt to major transportation disruptions, and how that information can be used to limit the economic consequences of large-scale transportation damage.

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