Natural Disasters and Plant Survival:

The Impact of the Kobe Earthquake

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INTRODUCTION

- Natural disasters can have a devastating impact on infrastructure, households and firms in the affected area

- Understanding what exactly this impact is can aid in disaster preparedness and mitigation

- There has been surprisingly little research and most of what has been done has tended to focus on cross-country and regional studies that estimate the overall impact of particular events on economic growth (Loayza *et al*. 2009, Hochrainer 2009, Hallegatte and Dumas 2009 and Ahlerup 2013)

- Result: generally only short-term negative or positive impact

INTRODUCTION

- Of the different types of natural disaster earthquakes represent one of the most devastating

- Earthquake damage can be primary and secondary consisting of physical damage to buildings and infrastructure and disruption to electricity/gas/water supplies

- Earthquakes can also have a unique impact on plant activity as plants in a relatively small geographical area can be impacted very differently

THIS PAPER

- We examine the impact of the Kobe EQ on plant performance

Relevant Literature:

- Kobe earthquake: Horwich (2000) – no net impact at the macro-level
- Firm level analysis:
  - Craioneanu & Terrell (2010) – larger firms are more likely to reopen after Hurricane Katrina;
  - Leiter et al (2009) employment growth in European firms is higher in regions with greater floods;
  - Hosono et al (2012) firms' investment decreases with banks in more affected Kobe regions
- But: These all use regional or imprecise measures of actual damage

THIS PAPER

Our contribution:

- Using geo-coding techniques we generate a measure of the damage incurred by individual buildings in the Kobe earthquake zone which we combine with manufacturing plant level data

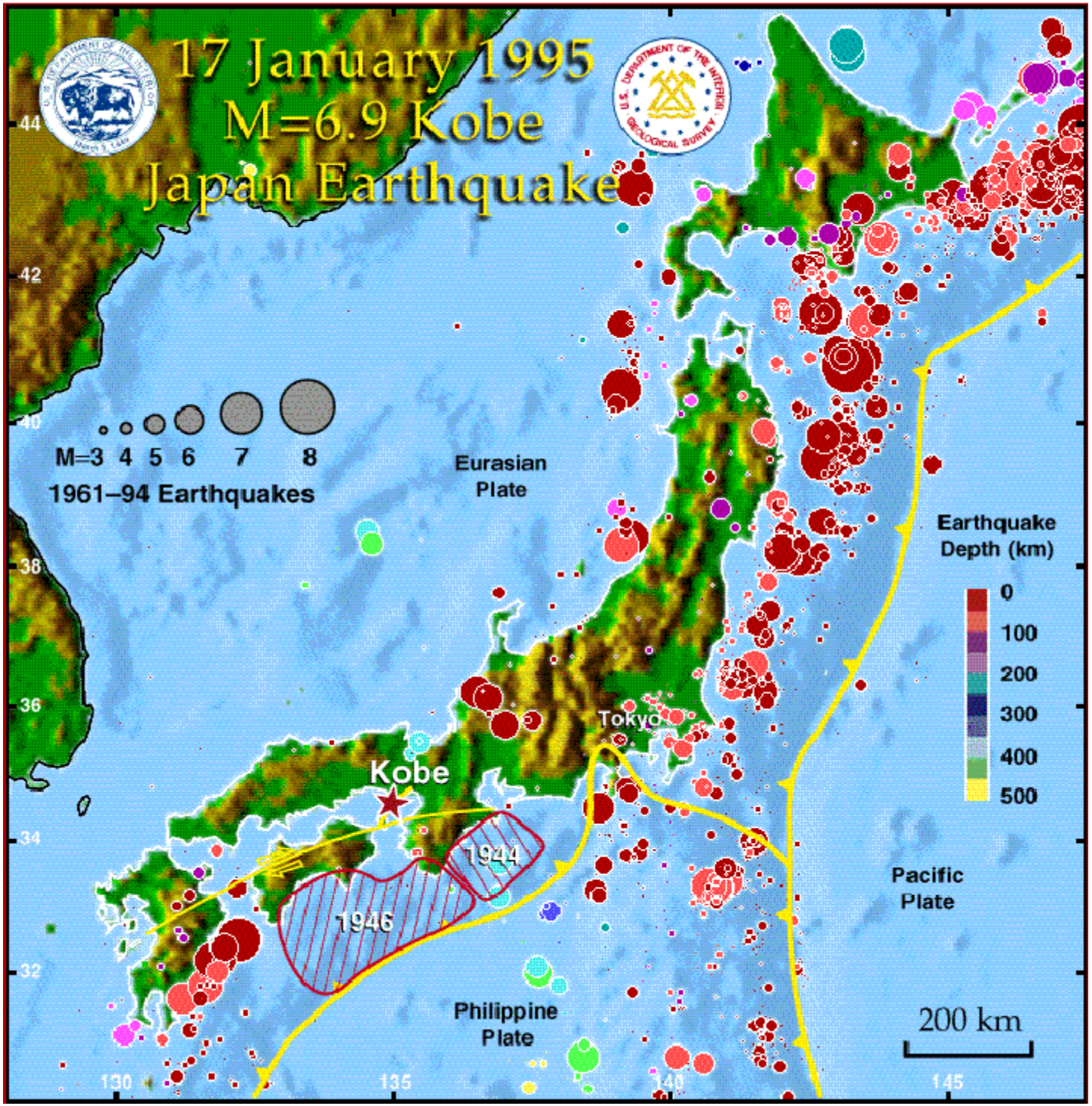
THE KOBE 1995 EARTHQUAKE

- Kobe is located 430 km southwest of Tokyo and is an important port city with close to 1.5 million people

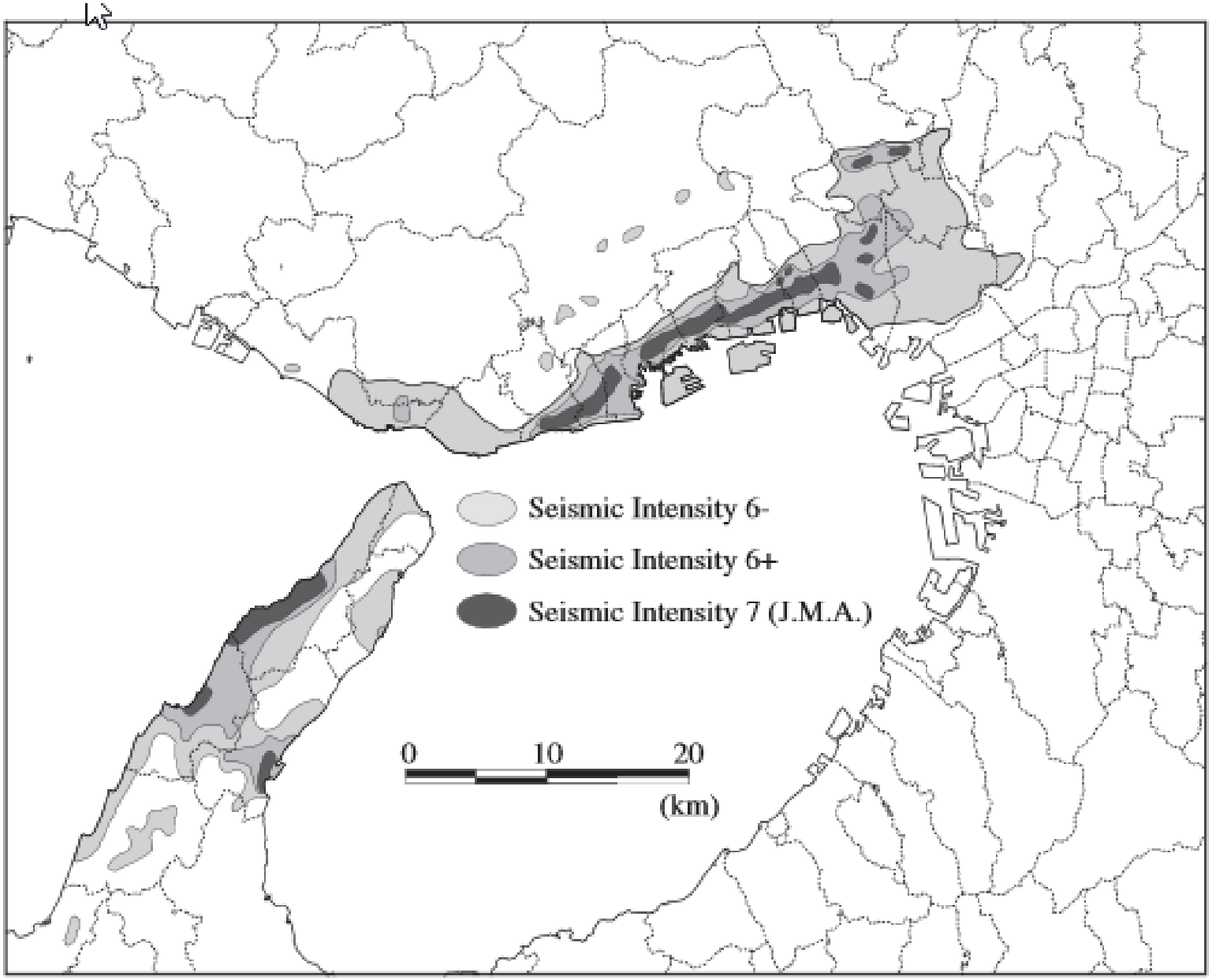
- Kobe (Great Hansin) EQ: hit the Hansin region of Western Japan that includes the city of Kobe on the 17th of January 1995 at 5:46am

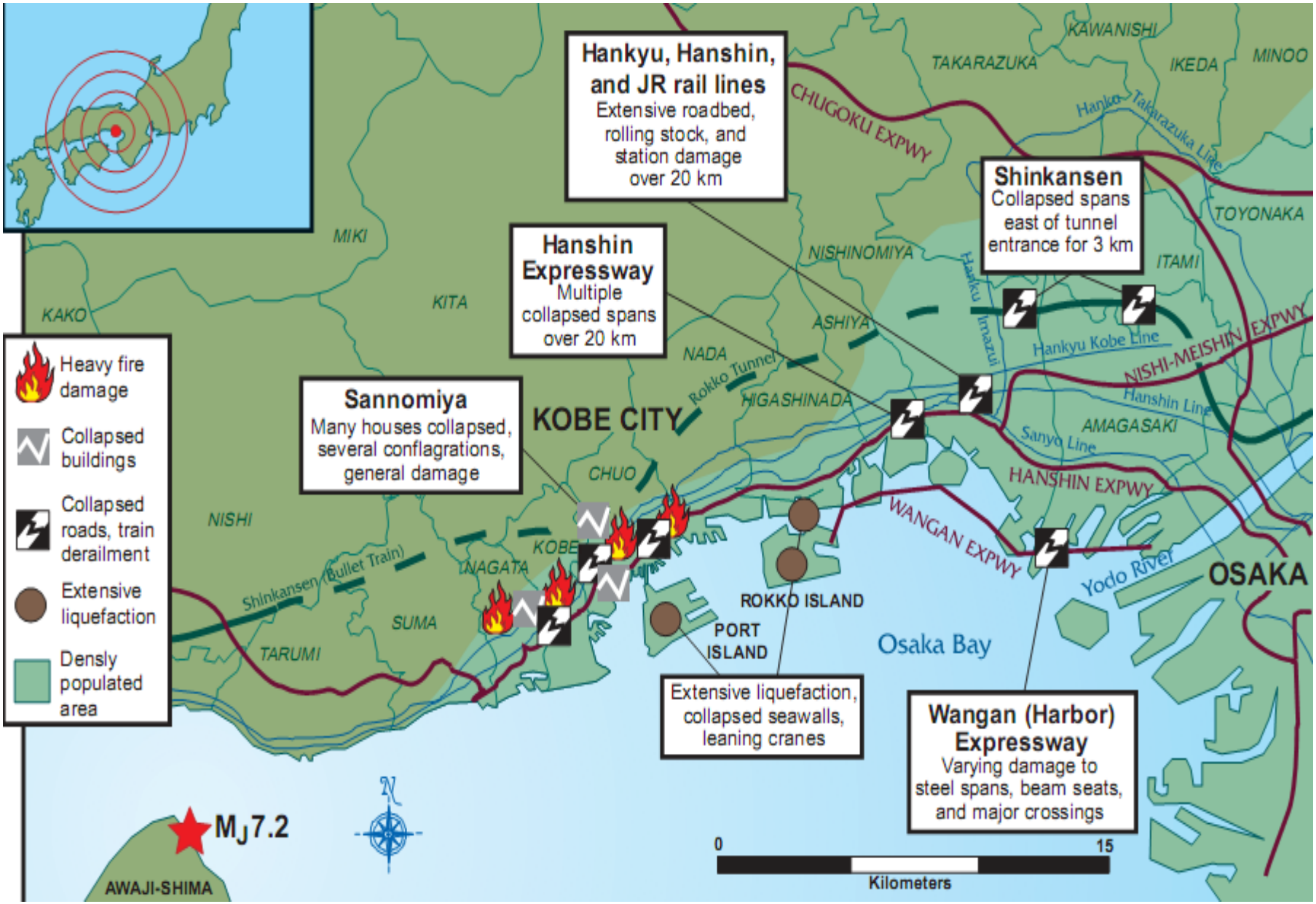
- The earthquake lasted about 20 seconds with a strength of 7.2 on the Richter scale (6.8 M_W)

- The epicenter was 25km from central Kobe and was the first major earthquake to strike a Japanese urban area since the end of WWII


17 January 1995
M=6.9 Kobe
Japan Earthquake
M=3 4 5 6 7 8
1961–94 Earthquakes
Eurasian
Plate
Earthquake
Depth (km)
0
100
200
300
400
500
Tokyo
Kobe
1944
1946
Pacific
Plate
Philippine
Plate
200 km
44
42
40
38
36
34
32
130
135
140
145

Observed seismic intensity map (Fujimoto & Midorikawa 2002)




Hankyu, Hanshin, and JR rail lines
Extensive roadbed, rolling stock, and station damage over 20 km
Shinkansen
Collapsed spans east of tunnel entrance for 3 km
Hanshin Expressway
Multiple collapsed spans over 20 km
Sannomiya
Many houses collapsed, several conflagrations, general damage
Heavy fire damage
Collapsed buildings
Collapsed roads, train derailment
Extensive liquefaction
Densly populated area
Extensive liquefaction, collapsed seawalls, leaning cranes
Wangan (Harbor) Expressway
Varying damage to steel spans, beam seats, and major crossings
KOBE CITY
OSAKA
Osaka Bay
ROKKO ISLAND
PORT ISLAND
AWAJI-SHIMA
MJ7.2
CHUGOKU EXPWY
HANSHIN EXPWY
WANGAN EXPWY
NISHI-MEISHIN EXPWY
Hankyu Kobe Line
Hanshin Line
Sanyo Line
Shinkansen (Bullet Train)
Rokko Tunnel
Yodo River
TAKARAZUKA
KAWANISHI
IKEDA
MINOO
TOYONAKA
ITAMI
NISHINOMIYA
ASHIYA
NADA
HIGASHINADA
AMAGASAKI
CHUO
NISHI
KOBE
NAGATA
SUMA
TARUMI
KITA
MIKI
KAKO
0
15
Kilometers

DESTRUCTION

People:

- 4,571 people were killed
- 14,687 injured
- 250,000 evacuated

Buildings:

- 67,421 or 15% of buildings were destroyed
- 55,145 partially collapsed
- The port was closed
- More damage was caused by fire – 54 immediate fires, 175 in total destroying another 6,965 buildings
- Overall more than 180,000 buildings damaged to some extent
- Total damage costs estimated to be around 6.9 trillion Yen

DESTRUCTION

Infrastructure:

- City-wide power failure – 7 days to restoration
- 25% phone outage – 15 days to restoration
- Almost total water and industrial water failure – 91 and 84 days to restoration respectively
- 80% gas failure – 85 days to restoration
- No refuse collection

- 130km of railway network closed
- Two artery lines partly closed
- Hanshin expressway closed
- Meishin expressway closed
- 27 roads damaged

WHAT DETERMINES EQ DESTRUCTION?

1. Magnitude
2. Depth
3. Distance from Epicenter
4. Local Geological Conditions
5. Architecture
6. Secondary Effects

WHY WAS KOBE EQ SO DESTRUCTIVE?

- *Northbridge EQ* (California) – 1994 in Los Angeles, Magnitude 6.7 M_W: 60 fatalities; 8,700 injured; relatively minor building and infrastructure damage

- Reasons for difference in damage:

  1. Much structural damage (and deaths) in traditional buildings not complying with 1981 seismic code
  2. Most of newer buildings were built on very soft, alluvial soil
  3. Many fires broke out

DATA

Manufacturing Plant Data:

- We utilise the Japanese Manufacturing Census and the Establishment and Enterprise Census - 1,846 manufacturing plants in Kobe city from 1992 to 2007
- Plants are followed until their death or until the end of our sample period in 2008
- The Manufacturing Census and the Establishment and Enterprise Census are exhaustive with no minimum size for inclusion
- Contains information on: exact address, sector, production, employment, wages, age, etc.

Summary Statistics

Industry	% of Sample	All Damage	Industry	% of Sample	All Damage
Non-Ferrous Metals	0.6	85.4	Wood Lumber	1.8	58.3
Rubber	17	76.2	Electronic Mach.	3	56.5
Leather & Fur	6.8	74.8	Transport Mach.	5.1	56.2
Inf. & Comm. Mach.	0.4	71.6	Chemicals	1.2	55.6
Pulp, Paper	2.5	71.5	Beverag. & Tobac.	2.1	55.5
Furniture	1.4	70.9	Food	12.3	54.6
Industrial Machinery	6	69.1	Electronics	0.6	52.1
Printing	10.5	68.1	Oil and Coal Prod.	0.5	49.4
General Machinery	4.6	63.4	Other Manuf.	4.6	47.8
Textiles	4.8	62.4	Porcelain & Pottery	1.3	42.9
Plastic Products	1.8	60	Household Machin.	0.8	39.7
Metal Products	8.6	59.3	Iron and Steel	1.3	35.4
Wood Lumber	1.8	58.3	Newspapers	0.6	23.5

DATA

Damage Data:

- Source: (1) ‘Shinsai Hukkou Akaibu’ (archive on the damage of the 1995 Hyogo-Awaji earthquake) by Kobe City Office; (2) Toru Fukushima (University of Hyogo), (3) ‘Zenrin’s Residential Map, Hyogo-ken Kobe city 1995’ from Toru Fukushima (University of Hyogo)

- These sources provide a highly detailed building map of Kobe and assign one of 5 colours to each building to categorize damage

MEASURING DAMAGE

No Damage (0-3% of value)

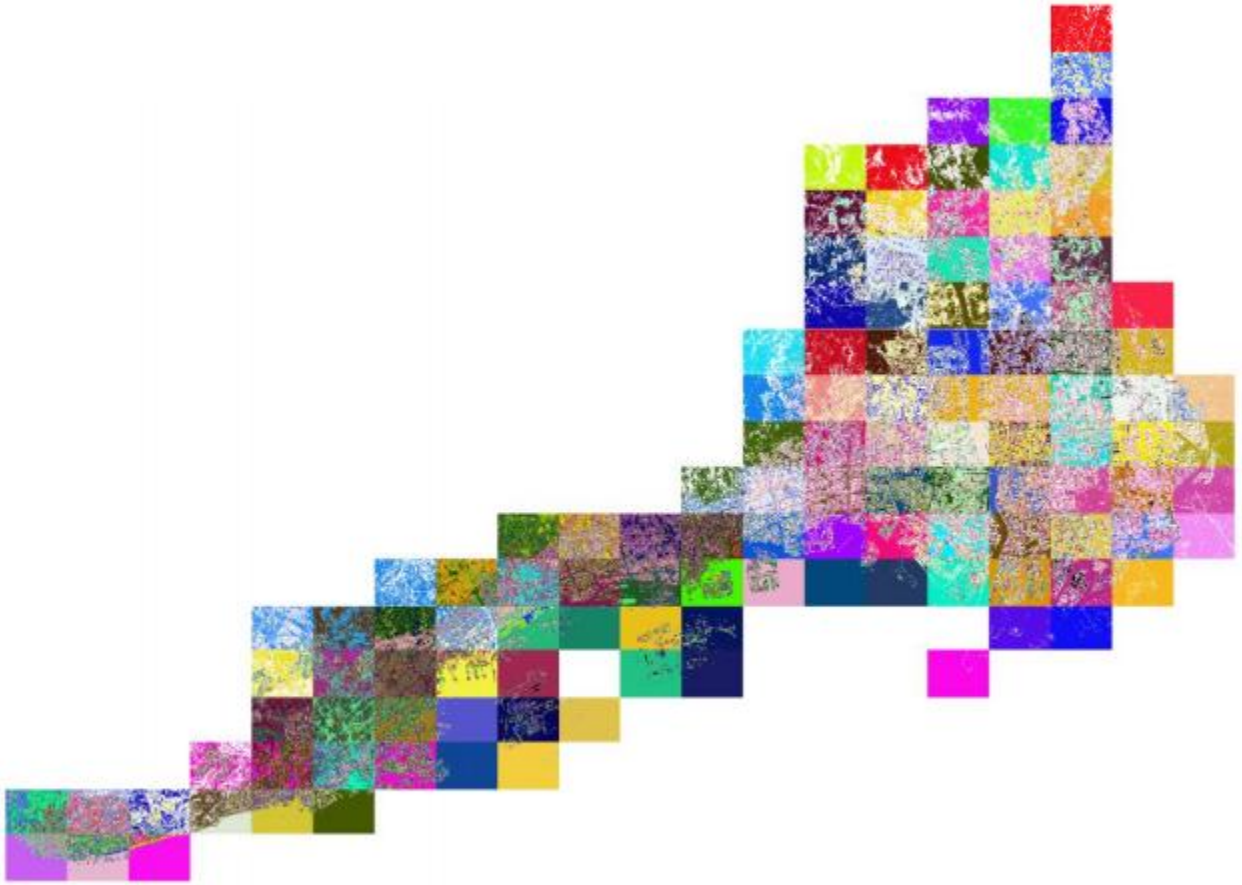
PartiallyCollapsed (3-20% of value)

Half collapsed (Damage 20-50%)
Buildings whose damage to principal supporting structures (walls, pillars, beams, roof, stairs) amounts to more than 20-50% of the current value of the building

Fully collapsed (Damage 50-100%)
Buildings whose damage to principal supporting structures (walls, pillars, beams, roof, stairs) amounts to more than 50% of the current value of the building

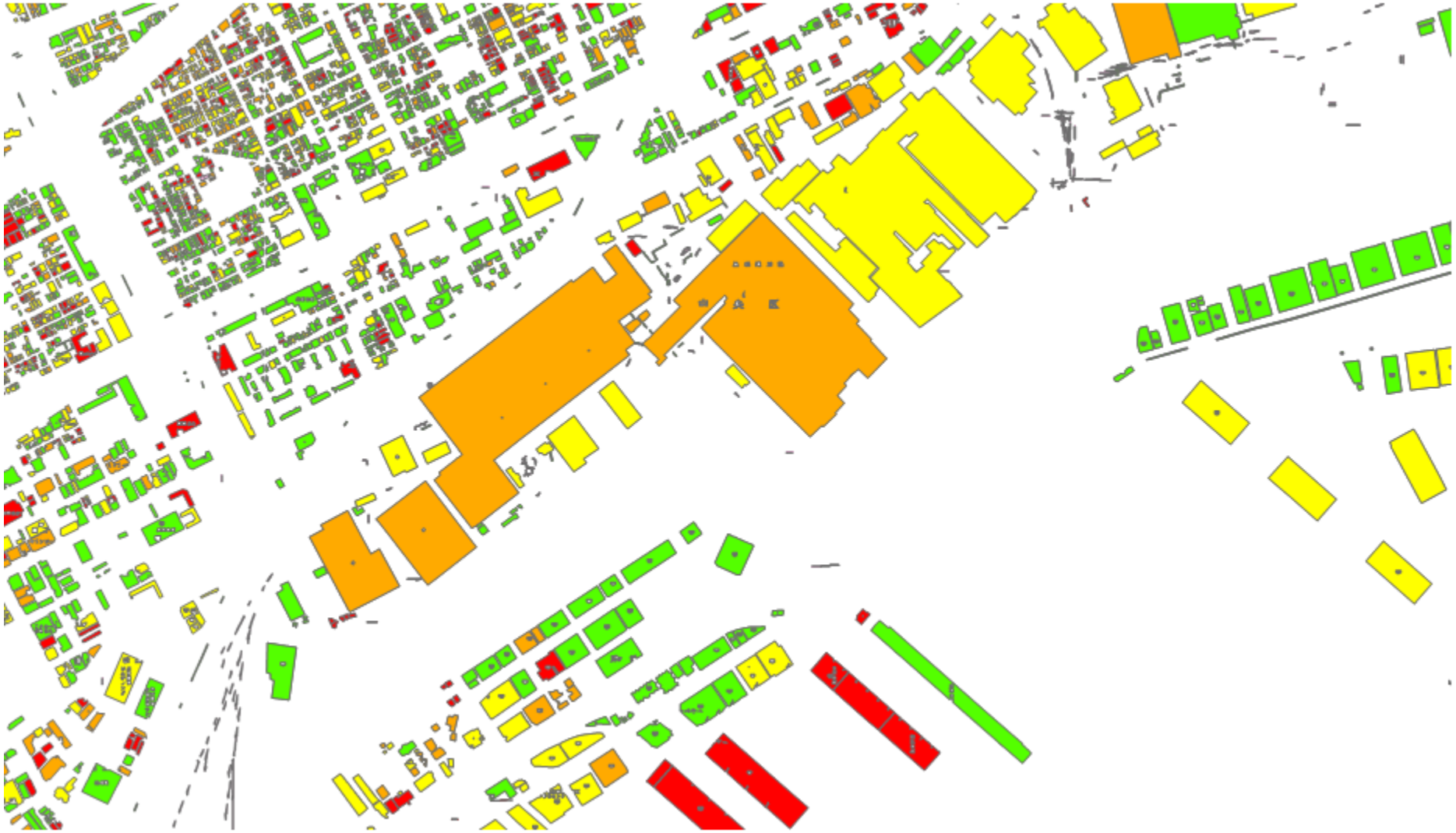
Fire damage (50-100%)

Map Tiles



Raw Map Data

Cleaned Map Data



Damage Index

We locate each plant to a building and then create Building Damage Index:

No Damage (0-3% of value) → **0%**

PartiallyCollapsed (3-20% of value) → **11.5%**

Half collapsed (Damage 20-50%) → **35%**

Fully collapsed (Damage 50-100%) → **75%**

Fire damage (50-100%) → **75%**

- We also create an equivalent Chomi level index of damages

Summary Statistics

Industry	% of Sample	All Damage	Industry	% of Sample	All Damage
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Rubber	17	76.2	Electronic Mach.	3	56.5
Leather & Fur	6.8	74.8	Transport Mach.	5.1	56.2
Inf. & Comm. Mach.	0.4	71.6	Chemicals	1.2	55.6
Pulp, Paper	2.5	71.5	Beverag. & Tobac.	2.1	55.5
Furniture	1.4	70.9	Food	12.3	54.6
Industrial Machinery	6	69.1	Electronics	0.6	52.1
Printing	10.5	68.1	Oil and Coal Prod.	0.5	49.4
General Machinery	4.6	63.4	Other Manuf.	4.6	47.8
Textiles	4.8	62.4	Porcelain & Pottery	1.3	42.9
Plastic Products	1.8	60	Household Machin.	0.8	39.7
Metal Products	8.6	59.3	Iron and Steel	1.3	35.4
Wood Lumber	1.8	58.3	Newspapers	0.6	23.5

Estimation

- Goal: Estimate impact on survival and post survival performance

Y= f(damage index, X)

- Is the damage index truly exogenous?

- (1) The Kobe earthquake as an exogenous shock

- (2) EQs are spatial phenomena

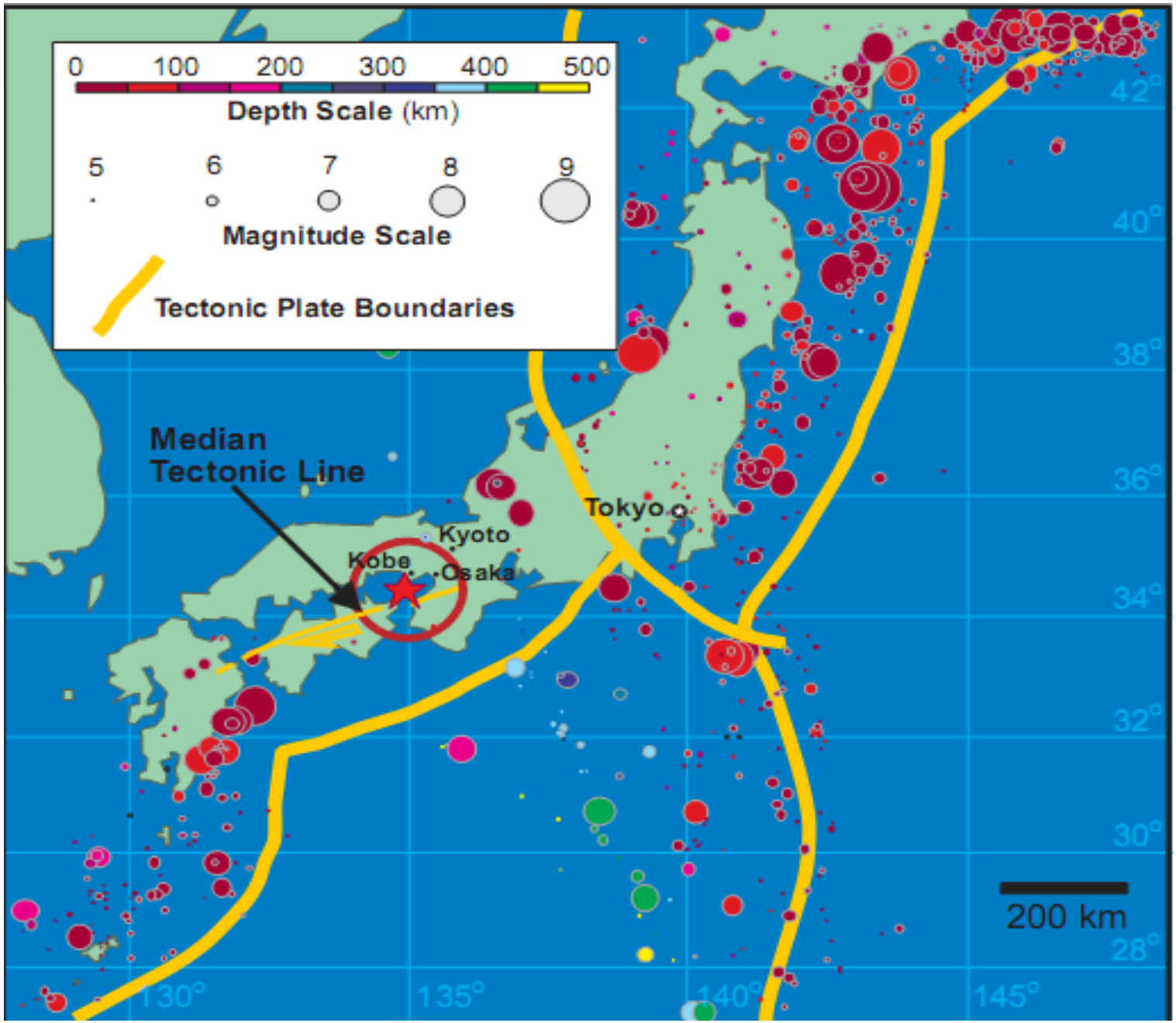
Estimation

- (1) The Kobe earthquake was arguably an unanticipated shock

"The news that Kobe was directly hit by an earthquake had major repercussions throughout Japan, particularly because of the enormity of the damage and, at the same time, due to the fact that Kobe could be struck by an earthquake. During the 1,500 years that earthquake occurrence has been recorded in Japan, not once has Kobe been directly hit by an earthquake and it has always had the image of being a city safe from earthquakes" **Kaji Hideki, UNRCD Director**

"Few businesses or private households held earthquake insurance. Indeed, most losses were uninsured: only 3% of property in the Kobe area was covered by earthquake indemnity, compared to 16% in Tokyo." **(Edington, 2010)**

Estimation


0 100 200 300 400 500
Depth Scale (km)
5 6 7 8 9
Magnitude Scale
Tectonic Plate Boundaries
Median
Tectonic Line
Tokyo
Kyoto
Kobe
Osaka
200 km
42°
40°
38°
36°
34°
32°
30°
28°
130°
135°
140°
145°

Estimation

- (2) EQs are spatial phenomena

- So we also control for:

  a. *Chomi level characteristics*: share of buildings by type (cement, wood, brick, iron); share of buildings by age category;

  b. *Plant level characteristics*: Age, size, wage, TFP, sector, whether moved, whether multi-plant etc.

Survival Analysis

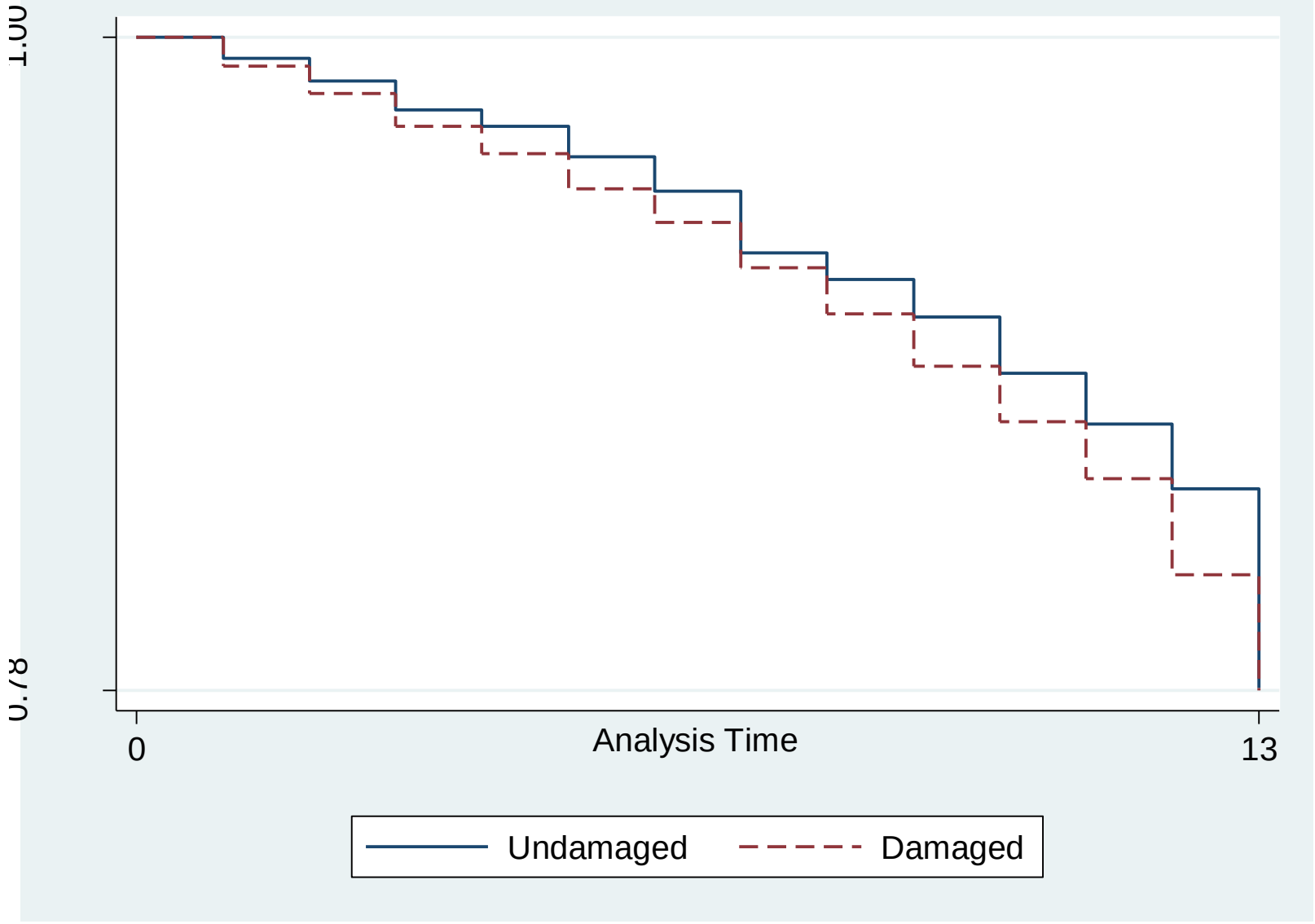
Kaplan-Meier Survival Function:

$$\hat{S}(t) = \prod_{t_j<t} \frac{n_j - d_j}{n_j}$$

n_j: number of plants

d_j: number of plant deaths

Kaplan-Meier survival curves for damaged and undamaged plants



Damage = Pink + Red + Orange + Yellow Categories

Survival Analysis

Following the literature on plant survival (Disney et al, 2003,Bernard et al, 2006, etc.) we estimate Cox-Proportional Hazards Model (Cox, 1972):

$$\lambda_{it} = \lambda_0(t)exp(Z\beta)$$

$\lambda_0(t)$: the baseline hazard

Z: vector of explanatory variables

β : parameters to be estimated.

Cox Proportional Hazard Model of Plant Survival

	2	3	4	5	6	7
DISTEPI	1.01***					
	(3.9)					
SHAKE		0.99				
		(-0.3)				
CHOME-damage			1.12		1.06	1.79***
			(1.3)		(0.7)	(6.8)
ROAD-damage			1.11		1.09	1.28**
			(1.4)		(1.2)	(2.0)
BUILDING-damage				1.61***	1.58***	3.01***
				(4.1)	(3.8)	(5.7)
*CHOME-damage*Time*						0.87***
						(-5.9)
*ROAD-damage*Time*						0.97*
						(-1.7)
*BUILDING-damage *Time*						0.87***
						(-4.3)

Controls: Time since EQ, Age, Wage, Size, TFP, Whether Moved, Industry dummies, Regional Dummies, Multi-plant dummy, Reconstruction Zone Dummy, Controls for Chomi-level Building Age and Type

Shake Map

Cox Proportional Hazard Model of Plant Survival

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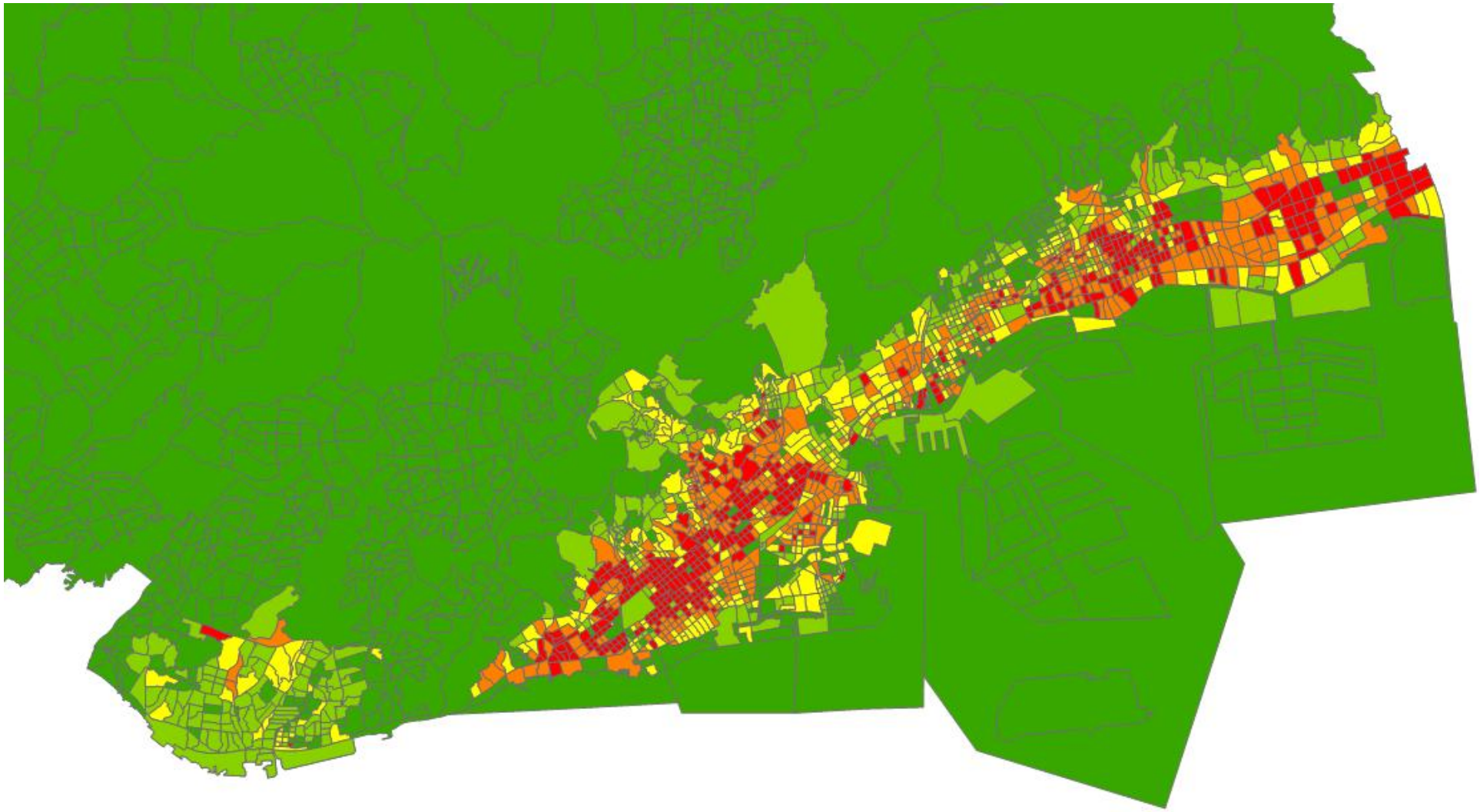
Shakemap Overlaying Damaged Buildings Map

Dominant Damage at Chomi Level



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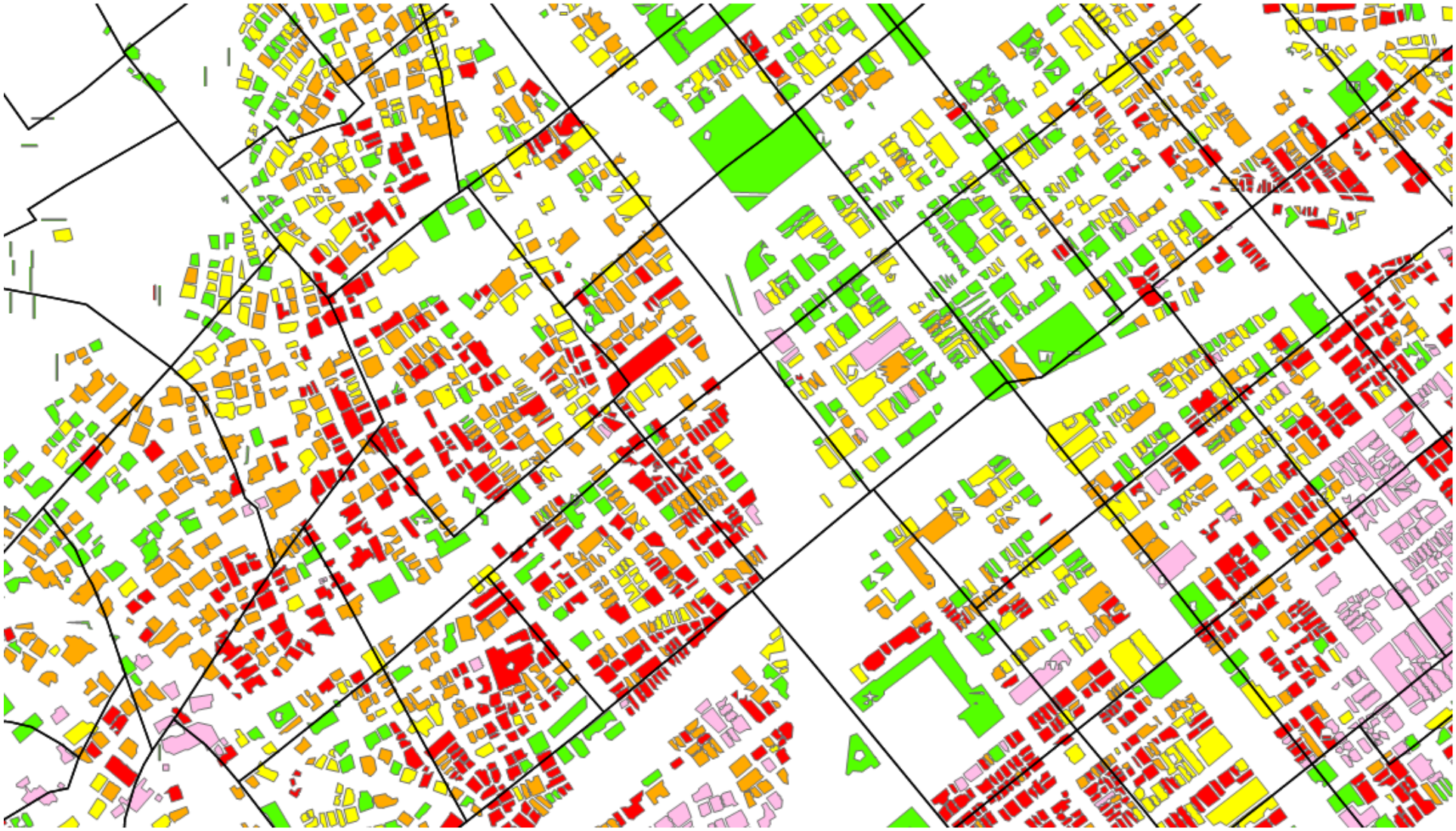
Example of Within Chomi Damage Heterogeneity



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						(-4.3)

Controls: Time since EQ, Age, Wage, Size, TFP, Whether Moved, Industry dummies, Regional Dummies, Multi-plant dummy, Reconstruction Zone Dummy, Controls for Chomi-level Building Age and Type

Damage Impact over time

Impact is unlikely to be permanent, but may vary over time because of:

1. Plants may struggle before they shut down

2. Government Aid may help some of them to survive for some time

Cox Proportional Hazard Model of Plant Survival

	2	3	4	5	6	7
DISTEPI	1.01***					
	(3.9)					
SHAKE		0.99				
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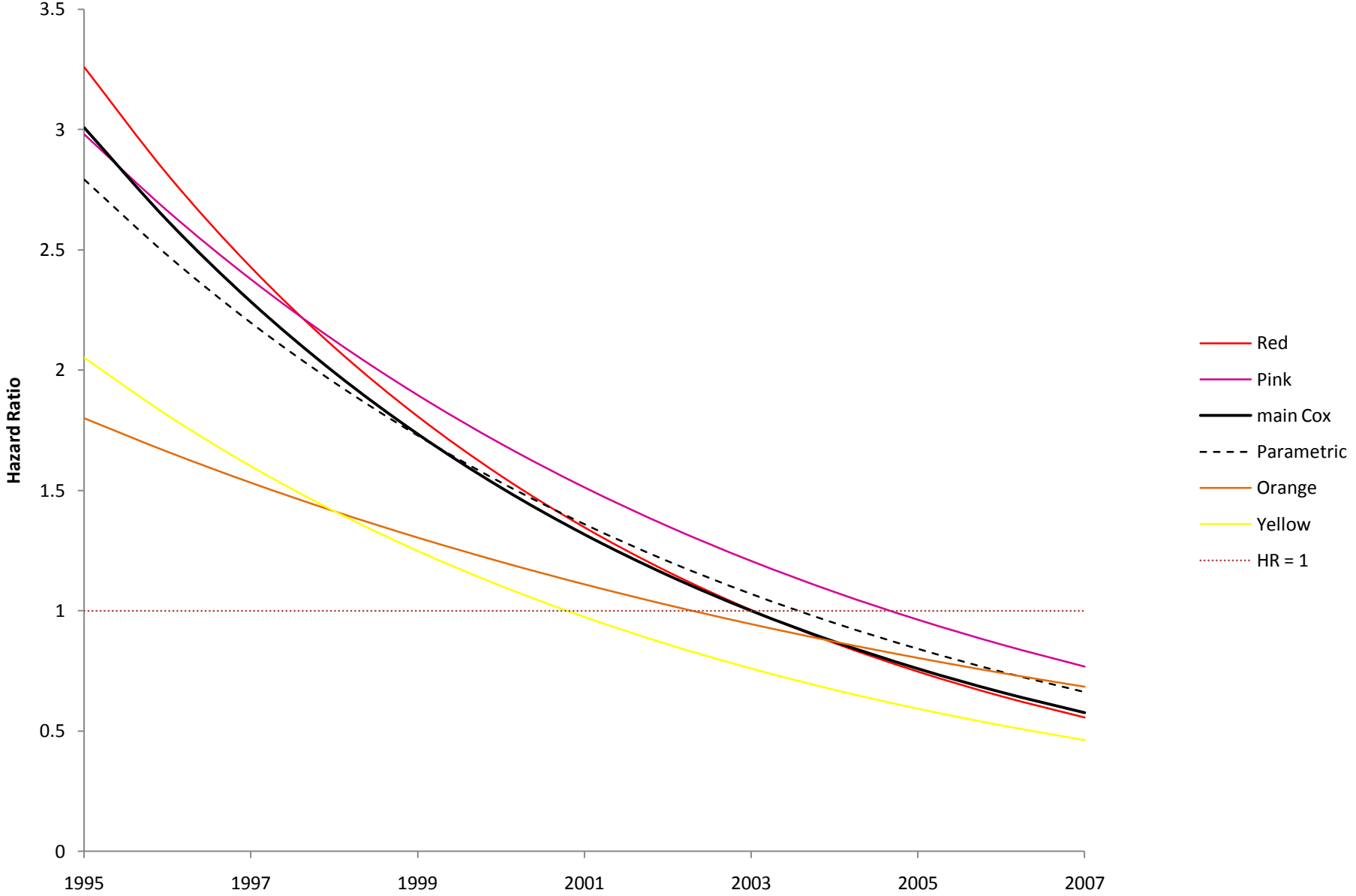
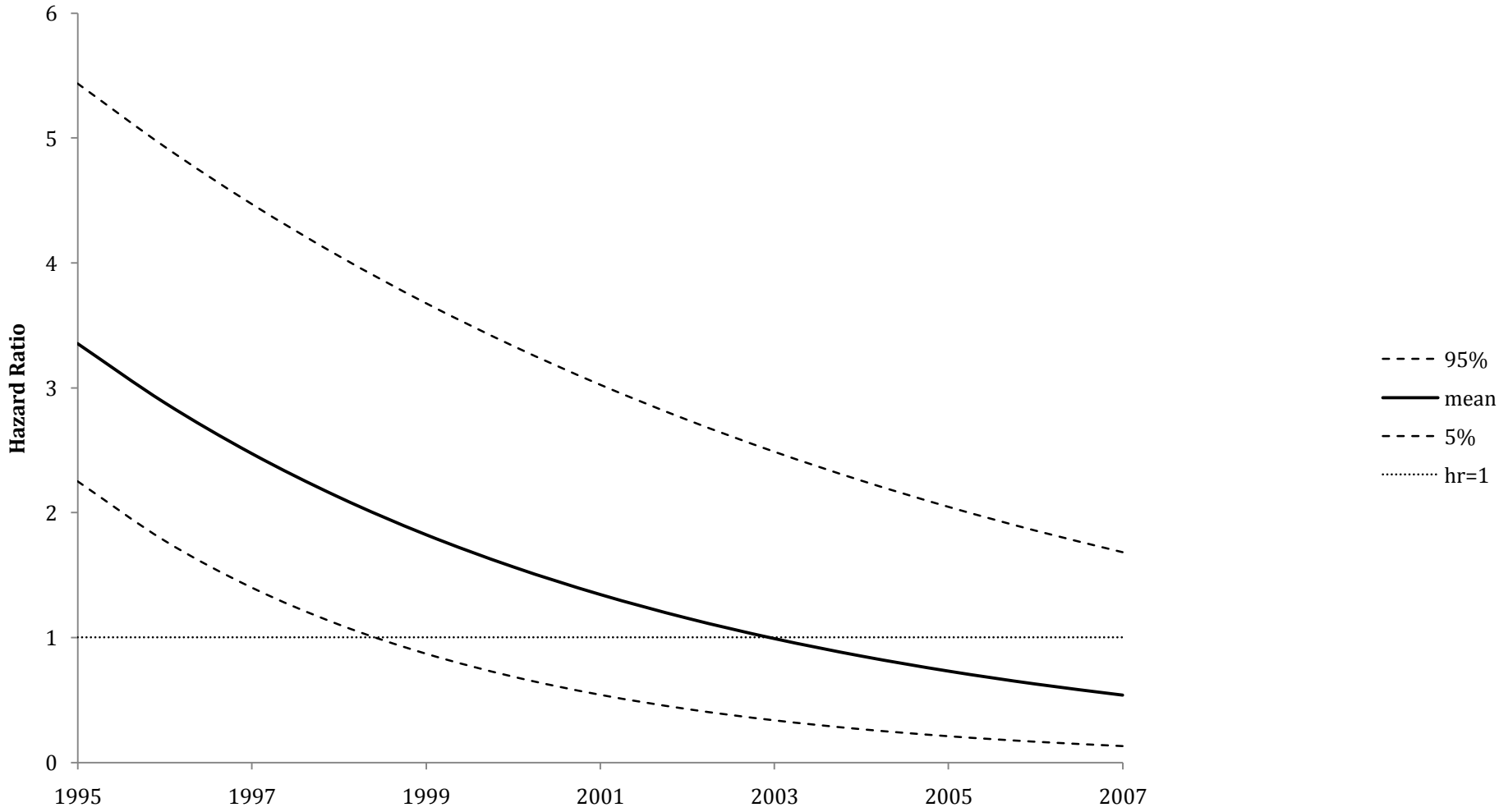
Survival analysis sensitivity results –Coefficients on Bld-Damage Dummies

Damage-pink	2.98***
	(3.2)
Damage-red	3.26***
	(5.9)
Damage-orange	1.80***
	(2.9)
Damage-yellow	2.05***
	(4.0)
*Damage-pink*Time*	0.89**
	(-2.2)
*Damage-red*Time*	0.86***
	(-5.4)
*Damage-orange*Time*	0.92***
	(-3.0)
*Damage-yellow*Time*	0.88***
	(-5.4)

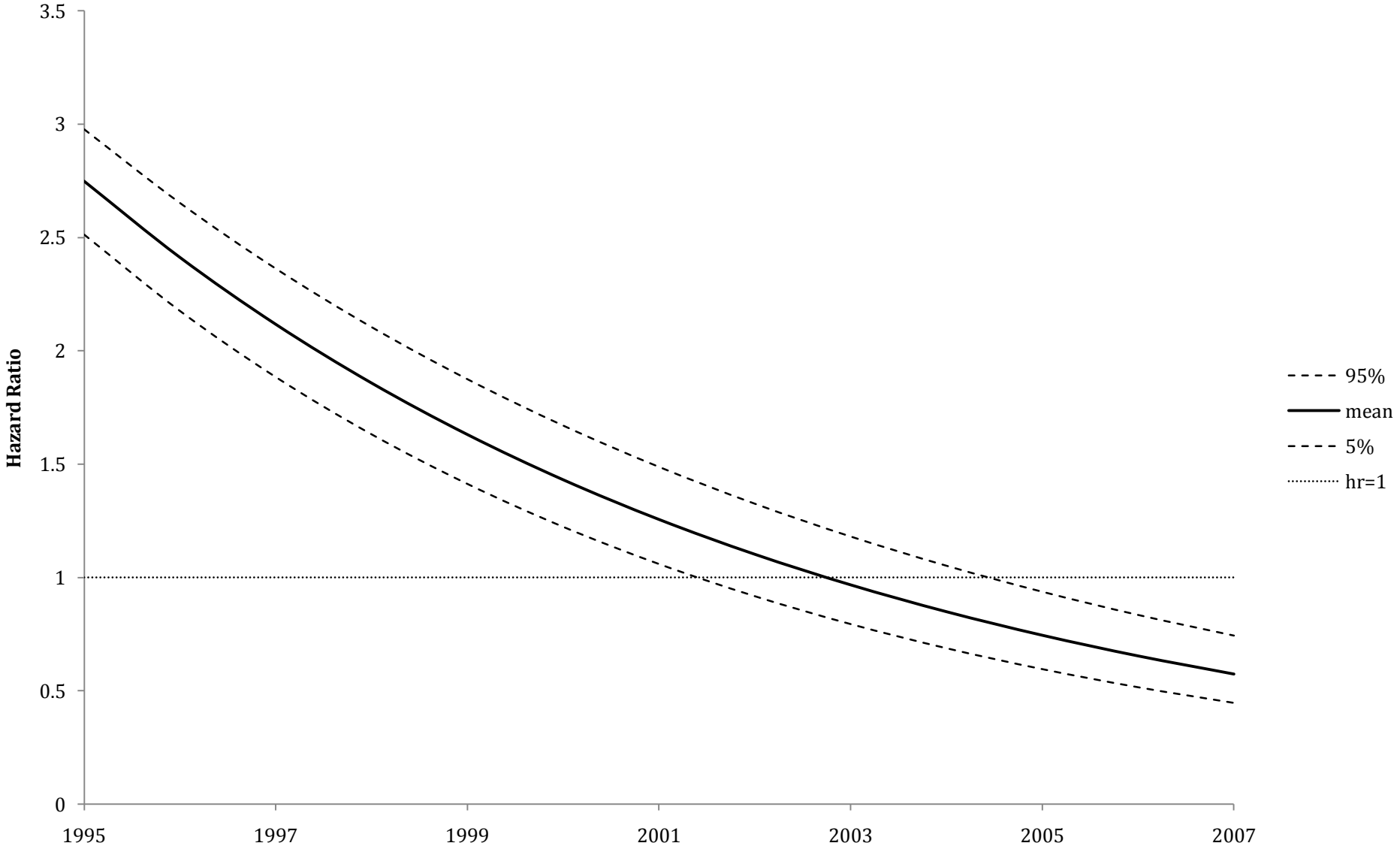
Damage hazard ratios over time



Damage hazard ratios over time - within a damage category same random damage %



Damage hazard ratios over time – within category random damage %



Creative Destruction?

Literature:

We examine two channels:

1. Impact on Survivors – fixed effects estimator; Unit of analysis: plants -level ; period 1992-2008
2. New Entrants – Negative Binomial Model; Unit of analysis: Chomi level; period: 1992-2008

Impact on VA, Emp., TFP & Labor Productivity 1992-2008

	logEmp	logEmp	logVA	logVA	TFP	TFP	logLP	logLP
Bld-Dg	-0.067***	-0.071***	-0.045*	0.030	0.023	0.099***	0.017	0.097***
	(-9.9)	(-4.8)	(-1.8)	(0.7)	(0.9)	(3.8)	(0.7)	(2.8)
*Bld-Dg *t*		0.00058		-0.011**		-0.011***		-0.011***
		(0.2)		(-2.1)		(-4.8)		(-3.4)
CH-Dg	-0.041***	-0.029***	-0.037**	-0.044**	-0.0057	0.011	0.0043	-0.014
	(-7.8)	(-3.8)	(-2.6)	(-2.7)	(-0.6)	(1.2)	(0.3)	(1.2)
*CH-Dg*t*		-0.0017*		0.0010		-0.0024**		0.0026
		(-1.8)		(0.4)		(-2.0)		(1.5)
Rd-Dg	-0.0032	0.00034	-0.037**	-0.067***	-0.0062	-0.055***	-0.034**	-0.066***
	(-1.0)	(0.1)	(-2.7)	(-7.3)	(-0.4)	(-5.8)	(-2.5)	(8.9)
*Rd-Dg*t*		-0.00050		0.0042*		0.0070***		0.0045**
		(-0.5)		(1.9)		(3.0)		(2.2)

Controls: Plant fixed effects, time since EQ, Age, Wage, Size and time dummies

Impact on Plant Births

	1	2	3	4
CHOMEdamage	-0.97***	-0.94***		
	(-4.9)	(-4.1)		
*CHOMEdamage*Time*		-0.0049		
		(-0.2)		
CHOMEdamagePink			-0.35	0.52
			(-1.0)	(1.3)
CHOMEdamageRed			0.65**	1.46***
			(2.0)	(3.8)
CHOMEdamageOrange			-1.43***	-1.72***
			(-3.1)	(-3.0)
CHOMEdamageYellow			-0.80**	-0.38***
			(-2.4)	(-0.9)
*CHOMEdamagePink*Time*				-0.14***
				(-3.3)
*CHOMEdamageRed*Time*				-0.12***
				(-3.6)
*CHOMEdamageOrange*Time*				0.047
				(0.8)
*CHOMEdamageYellow*Time*				-0.059
				(-1.5)

CONCLUSION

- We examined plant performance after the Kobe EQ using plant specific damage indicators and an exhaustive panel of manufacturing plants

- Findings: (1) negative impact on plant survival and this effect lasts over several years; (2) negative impact also on post- EQ plant performance, but also some small evidence of 'creative' destruction

- Future Research:

  - Our results are 'net' – what happens inside the 'black box'?
  - How were other parts of Japan indirectly affected?