

Risk prevention in cities prone to natural hazards

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Motivation

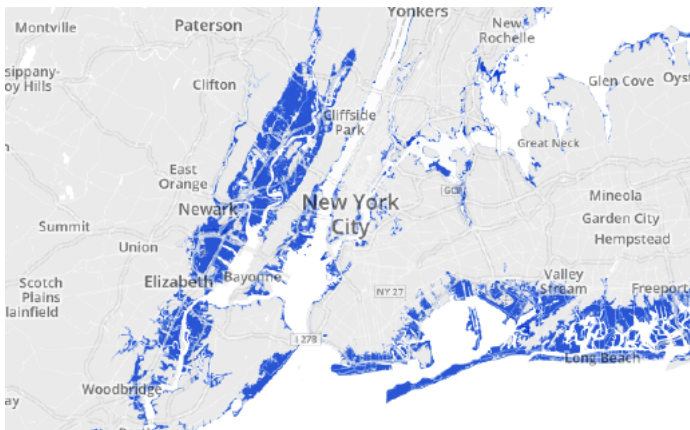


Figure: New York hit by Hurricane Sandy in October 2012 (Source: WNYC)

Questions

- ▶ How do cities spatially develop in terms of **density** and **resilience** at each location?
- ▶ What is the impact of **insurance subsidization** or **public relief** on city development?
- ▶ What **urban policies** should we implement in terms of density and resilience?
- ▶ How **urban growth and climate change** affect city development?

Results

▶ City development:

- ▶ Riskier areas are developed nearer to the city center than further away.
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- ▶ Actuarially fair insurance implements optimal housing density and building resilience.
- ▶ Insurance subsidization usually leads to housing over-development and resilience under-investment in risky areas.

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- ▶ Insurance subsidization usually leads to housing over-development and resilience under-investment in risky areas.

▶ **Long-term evolution:**

- ▶ Urban growth leads to housing density increase and building resilience increase.
- ▶ Climate change usually leads to density decrease and resilience increase.

Literature review

- ▶ theoretical:
 - ▶ natural disasters and urban density:
Polinsky and Shavell (1976); Scawthorn et al. (1982); Frame (1998,2001); Grislain-Letremy and Villeneuve (2014);
 - ▶ natural disasters, urban density and resilience investment:
the present paper
- ▶ empirical:
 - ▶ natural disasters and housing prices:
Shilling et al. (1989); McKenzie and Levendis (2008); Daniel et al. (2009); Atreya and Czajkowski (2014);
 - ▶ natural disasters and resilience investment:
Kunreuther et al. (1978); Burby et al. (1988); Czajkowski and Simmons (2013); Aerts, Michel-Kerjan et al. (2014).

Transport costs and natural hazards

Static spatial model with coordinates $x = (x_1, x_2)$.

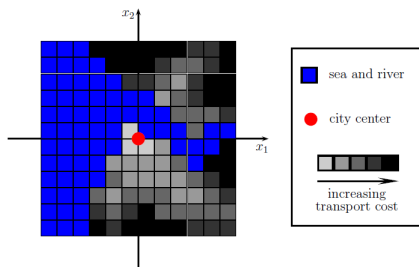


Figure: Commuting transport costs
 $t(x) = t(x_1, x_2)$

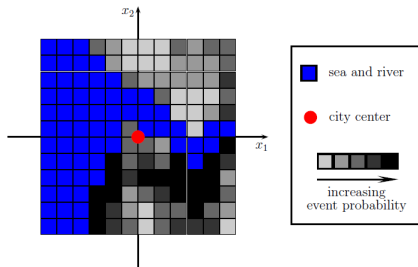


Figure: Natural disaster probabilities
 $\pi_\mu(x) = \pi_\mu(x_1, x_2)$

Housing developers and land markets

- ▶ Identical housing developers in competition:
 - ▶ they acquire land at unit price $p_l(x)$,
 - ▶ they develop housing services $H(x)$ per land unit with building resilience $B(x)$ per land unit at cost $C(H(x), B(x))$,
 - ▶ they sell housing at unit price $p_h(x)$.

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 - ▶ they sell housing at unit price $p_h(x)$.
- ▶ Because of competition, the land unit price is such that:

$$p_l(x) = \max_{H(x), B(x)} \left(p_h(x)H(x) - C(H(x), B(x)) \right) \quad (1)$$

s.t. $H(x) \geq 0, B(x) \geq 0$ and (2).

Households and housing markets

- ▶ N identical households in competition with utility function $v(z, h)$ and wealth \bar{y} :
 - ▶ they choose location x , composite good consumption $z(x)$ at unit price 1 and housing services $h(x)$ at unit price $p_h(x)$,
 - ▶ they incur commuting transports cost $t(x)$ and natural disaster costs $(1 - \lambda)\pi_\mu(x) \frac{h(x)}{H(x)} L(H(x), B(x)) + \bar{\tau}$.

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- ▶ Because of competition, the housing unit price is such that:

$$p_h(x) = \max_{z(x), h(x)} \frac{\bar{y} - z(x) - t(x) - (1 - \lambda)\pi_\mu(x) \frac{h(x)}{H(x)} L(H(x), B(x)) - \bar{\tau}}{h(x)}$$

$$s.t. v(z(x), h(x)) = \bar{v}.$$
(2)

Closing the model

- ▶ The city boundaries correspond to locations x such that $p_l(x) = \overline{p}_a$. The boundaries can also be characterized by an upper natural disaster probability $\pi_\mu^*(t)$ over which land is not developed.

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- ▶ With $n(x)$ the household density at location x , the clearing housing market condition and the population condition can be written:

$$n(x)h(x) = H(x),$$

$$N = \iint n(x) dx_1 dx_2.$$

Developed areas and city boundaries

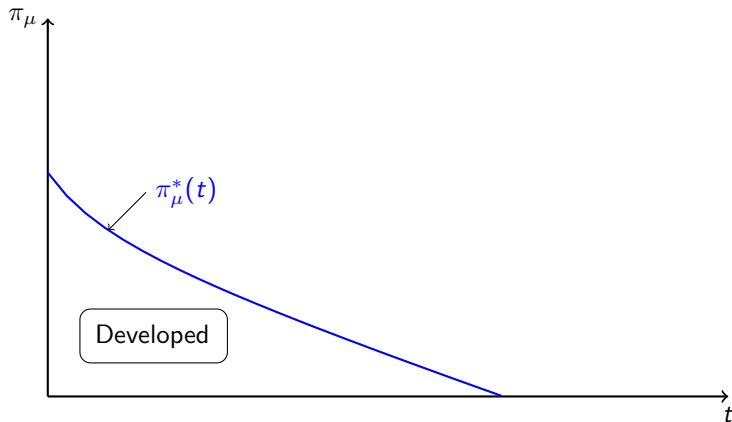


Figure: Developed areas (as a function of transport cost t and disaster risk π_μ)

Developed areas and city boundaries

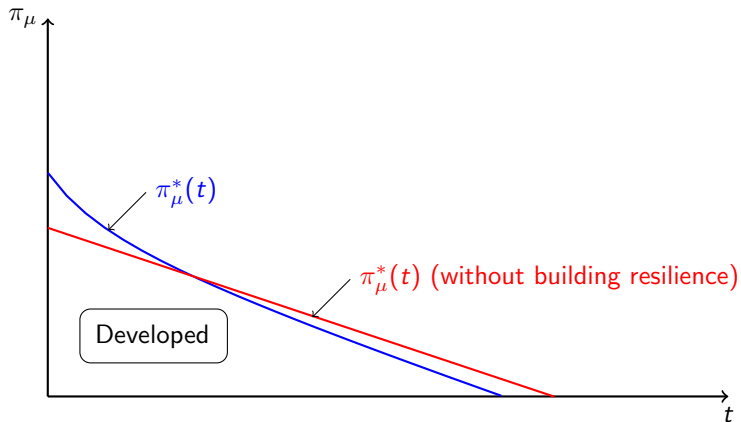


Figure: Developed areas (as a function of transport cost t and disaster risk π_μ)

Developed areas near New York city center



Figure: Extension of New York city center over water areas thanks to land fill
(Source: www.nyc.gov/)

Housing services and building resilience

- ▶ The housing density $H(x)$ and building resilience $B(x)$ vary in space as follows:

$$\frac{dH}{d\vec{x}} = \underbrace{-\frac{1}{h(x)A_1(x)} \frac{dt}{d\vec{x}}}_{<0} + \left(\underbrace{-\frac{(1-\lambda)}{A_1(x)} \frac{\partial L}{\partial H}}_{<0 \text{ (direct)}} + \underbrace{\frac{(1-\lambda)A_2(x)}{A_1(x)} \frac{\partial L}{\partial B}}_{>0 \text{ (indirect)}} \right) \frac{d\pi_\mu}{d\vec{x}},$$

$$\frac{dB}{d\vec{x}} = \underbrace{\frac{A_4(x)}{h(x)A_3(x)} \frac{dt}{d\vec{x}}}_{<0} + \left(\underbrace{-\frac{(1-\lambda)}{A_3(x)} \frac{\partial L}{\partial B}}_{>0 \text{ (direct)}} + \underbrace{\frac{(1-\lambda)A_4(x)}{A_3(x)} \frac{\partial L}{\partial H}}_{<0 \text{ (indirect)}} \right) \frac{d\pi_\mu}{d\vec{x}},$$

Actuarially fair insurance

- ▶ Actuarially fair insurance ($\lambda = 0$) leads to a Pareto-optimal allocation.

Insurance subsidies and developed areas

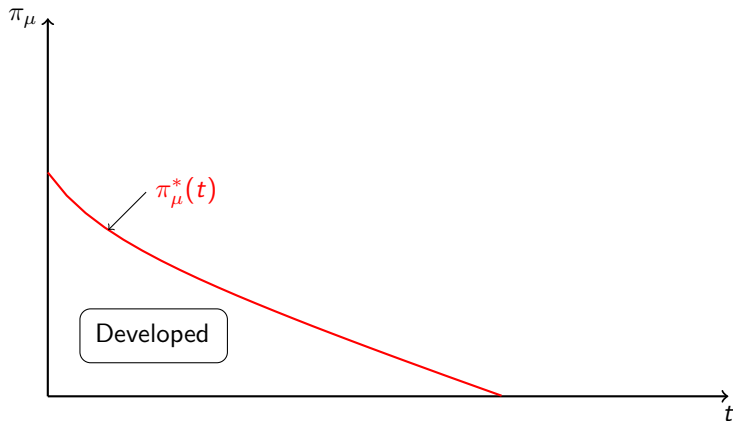


Figure: Developed areas with country subsidies

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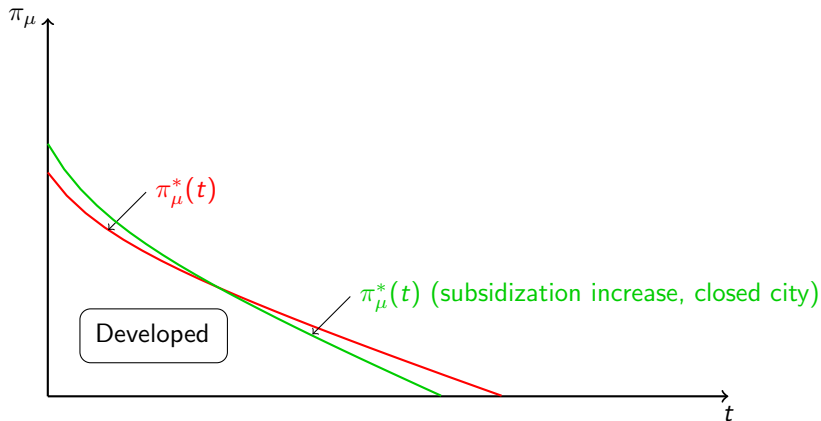


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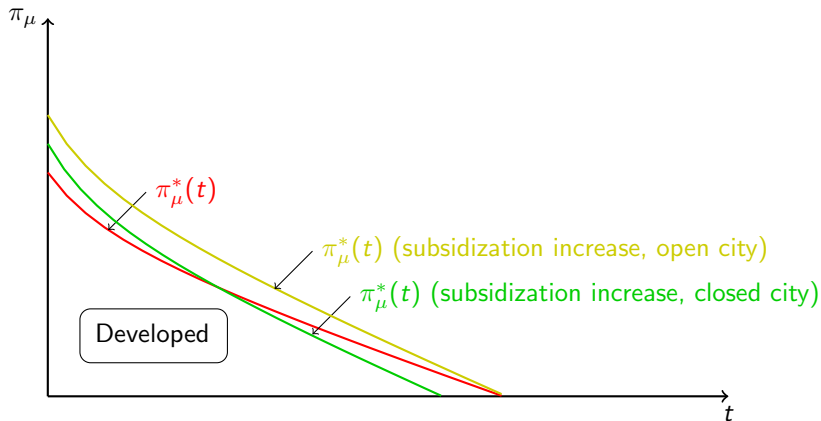


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Insurance subsidies, housing and resilience

- ▶ The increase of insurance subsidization has the following impact on urban development at each location x in the city:

$$\frac{dH(x)}{d\lambda} = \underbrace{\frac{\pi_\mu(x)}{A_1(x)} \frac{\partial L}{\partial H}}_{>0 \text{ (direct)}} - \underbrace{\frac{\pi_\mu(x)A_2(x)}{A_1(x)} \frac{\partial L}{\partial B}}_{>0 \text{ (indirect)}} - \underbrace{\frac{1}{h(x)A_1(x)} \frac{d\bar{\tau}}{d\lambda}}_{\geq 0}$$

$$\frac{dB(x)}{d\lambda} = \underbrace{\frac{\pi_\mu(x)}{A_3(x)} \frac{\partial L}{\partial B}}_{<0 \text{ (direct)}} - \underbrace{\frac{\pi_\mu(x)A_4(x)}{A_3(x)} \frac{\partial L}{\partial H}}_{<0 \text{ (indirect)}} + \underbrace{\frac{A_4(x)}{h(x)A_3(x)} \frac{d\bar{\tau}}{d\lambda}}_{\leq 0}$$

Urban growth

- ▶ With an open city, a wealth increase affects housing and resilience at each location x as follows:

$$\frac{dH(x)}{d\bar{y}} = \frac{1}{h(x)A_1(x)} > 0,$$

$$\frac{dB(x)}{d\bar{y}} = -\frac{A_4(x)}{h(x)A_3(x)} > 0.$$

Climate change

- ▶ With an open city, a risk increase affects housing and resilience at each location x as follows:

$$\frac{dH(x)}{d\mu} = \underbrace{\left(-\frac{(1-\lambda)}{A_1(x)} \frac{\partial L}{\partial H} \right)}_{<0 \text{ (direct)}} + \underbrace{\left(\frac{(1-\lambda)A_2(x)}{A_1(x)} \frac{\partial L}{\partial B} \right)}_{>0 \text{ (indirect)}} \frac{d\pi_\mu(x)}{d\mu},$$

$$\frac{dB(x)}{d\mu} = \underbrace{\left(-\frac{(1-\lambda)}{A_3(x)} \frac{\partial L}{\partial B} \right)}_{>0 \text{ (direct)}} + \underbrace{\left(\frac{(1-\lambda)A_4(x)}{A_3(x)} \frac{\partial L}{\partial H} \right)}_{<0 \text{ (indirect)}} \frac{d\pi_\mu(x)}{d\mu},$$

Conclusion

- ▶ **Role of resilience investment:**
 - ▶ Resilience investment allows to reallocate households from the outer boundary to risky areas near the city center.

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- ▶ **Policy recommendations:**
 - ▶ Actuarially fair insurance should be implemented to obtain optimal density and resilience.
 - ▶ In case of insurance subsidization, density restrictions and building codes can be enforced to limit risk over-exposure.

Conclusion

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 - ▶ Resilience investment allows to reallocate households from the outer boundary to risky areas near the city center.
- ▶ **Policy recommendations:**
 - ▶ Actuarially fair insurance should be implemented to obtain optimal density and resilience.
 - ▶ In case of insurance subsidization, density restrictions and building codes can be enforced to limit risk over-exposure.
- ▶ **Further works:**
 - ▶ Application and welfare analysis for a city such as New York.
 - ▶ Extension to household heterogeneity for inequality issues.