Land Reclamation, Wetland Reservation, and Flood Control: Optimal Policy, Spatial Externalities, and Strategic Behaviors

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Extended summary of the paper. Floods are catastrophic. By legends such as Noah's Ark in the Book of Genesis (Ch. 6–9) and the Chinese myth of the Great Flood of Gun–Yu (Wu et al., 2016), human civilizations across the world know well that social prosperity can never survive without successful flood control. In the short history of the United States, for example, flood control is essential in the development of California (Kelly, 1989; Hanak et al., 2011) and along the Mississippi River (Vigdor, 2008, p. 135; Jacobsen, 2011, p. 118). In other parts of the world, for example, "[i]n the Netherlands, flood protection is a matter of national survival" because of the low altitude of its territory (Eijgenraam et al., 2014).

The significance of flood control has been reemphasized in recent years by several extremely damaging disasters. After Hurricane Katrina in 2005 failed more than 50 levees and left New Orleans under water, Hurricane Harvey in 2017 ravaged the populous Houston metropolitan area with a comparable strike. When people in the United States debate how much the rapid, uncoordinated urban development that ate up wetlands and the drainage and retention capacities they had brought should be blamed (e.g., Jacob et al., 2012; Beyer, 2017; Campoy and Yanofsky, 2017; Herriges, 2017), Chinese researchers predict that one third to half of the Xiong–An New Area, a recently proposed, ambitious city building project in North China, will face significant flooding risks in the future (Ge et al., 2017). The Intergovernmental Panel on Climate Change (2014, p. 67) has also reported that "the fractions of the global population that will . . . be affected by major river floods are projected to increase with the level of warming in the 21st century," and climate change will increase flooding risks especially in Central and South America (p. 65) and in urban areas globally (p. 69). All these make the following questions even more pressing: how should investment in flood control facilities be combined with land development policies, and what would happen if wetland reservation were ignored? How would decentralized land development and flood control deviate from social optimality, and how would regional coordination and cooperation help to alleviate the problem?

To answer the questions, in this paper, we build a highly stylized model of a floodplain where a city planner decides how much wetlands to be converted into development and how high she would like to raise the city's levee against the flooding risk. We show that the physical property of water being a fluid implies that land development that acquires flood-retaining wetlands will create the need for levee building. Facing higher flooding risks under climate change, a policy portfolio including both wetland reservation and levee building should be adopted, and ignoring the wetland reservation can lead to overbuilding of flood control facilities.

To understand better strategic considerations in land development and flood control, we further analyze two extensions of the model. In the first extension, we consider multiple, independent land developers in the same floodplain and recognize the spatial externality of land reclamation – the less wetland is preserved, the higher the water level would be everywhere when a flood comes. We show that this spatial externality can cause a coordination game with multiple equilibria under decentralized land development. The potential coordination failure can result in under-preservation of wetlands. Regional coordination can then step in to help.

In the second extension, we consider decentralized levee building decisions and recognize the spatial externality of flood control facilities – higher levees at one place push water to other places where levees are lower. This beggar-thy-neighbour incentive can encourage cities to build their own levees a bit higher than each other, resulting in an arm race of levee building until no city would be flooded. This arm race introduces deadweight loss, since it is economically inefficient to guarantee that no city would be flooded. Land reclamation and climate change that moves the right tails of the flood risk further right can further aggravate the overbuilding of levees. Regional cooperation is then needed to address the overbuilding.

To illustrate our theoretical analysis, we have also numerical exercises in progress.

Exemplary links to literature. Our paper speaks to the economics literature on optimal investment in flood control facilities. Pioneered by van Dantzig (1956)'s classic *Econometrica* paper after the 1953 North Sea flood, a large portion of this literature takes flooding risks, often represented by the distribution of flooding water levels, as exogenous, especially in settings of costal flood management where the spatial externality of levees can arguably vanishes (e.g., the most recent progress by Eijgenraam et al., 2017). We endogenize the distribution of flooding water levels as dependent on land development decisions of all communities and on heights of all levees in the same floodplain, and this dependency drives all our results.

The potential link between land development decisions and flood control investments are well acknowledged by flood management experts. For example, Burby et al. (1988) evaluate 10 United States cities' floodplain land use management strategies. Foster and Giegengack (2006) focus on lessons from Hurricane Katrina for urban planning. Brody et al. (2008, 2011) and Brody and Highfield (2013) investigate how wetland reservation and land development affect flood damage. Using the Netherlands as an example, Brouwer and van Ek (2004) identify land use changes and floodplain restoration as important alternatives to structural measures such as building higher and stronger dikes. These studies are primarily either narrative, empirical, or numerical, while we hope our paper can provide a basic, analytical view.

On the strategic aspect of flood control and related land use policies, modeling the spatial externalities of these investments can yield several new insights. For example, economists traditionally consider investment in flood control measures as a public good, and underinvestment can emerge (e.g., Young and Haveman, 1985; Taylor, 1987; Gardner et al., 1990; Agthe et al., 2000). In our model, however, the spatial externality of levee building makes it a private good but public bad, so overinvestment can emerge. As another example, Dombrowsky (2007, p. 170–172) models the strategic provision of retention area at a border river as a prisoner's dilemma. We show that the spatial externality of land reclamation implies that a coordination game can be better micro-founded, suggesting that coordination regimes without payoff alternation could help to reach social optimality. Finally, Lünenbürger (2006) recognizes the spatial externality of flood control and focuses on the unidirectional spill-over in a upstream–downstream setting and its political implication in a voting setting; Grislain-Letrémy and de Forges (2015) follow with a focus on uniform insurance. The externality in our model is symmetric across different communities, which is arguably more general in a floodplain setting, and we explicitly model the micro-foundation of the externality.

There also exists a nascent, primarily numerical literature in hydrological engineering on the strategic aspect of flood control. For example, Croghan (2013) and Hui (2014, Ch. 2) illustrate that asymmetric levee heights can take advantage of risk trading when the flood damages are asymmetric, e.g., in their urban–rural setting. We show asymmetric levee heights can be optimal even when the flood damages are symmetric. A recent work by Hui et al. (2016) simulates two cases where decentralized investment in flood control facilities deviates from the centralized optimal solution, suggesting potential arm races of levee building. We provide a more general, analytical approach instead.

Our paper also links to the literature on flood insurance, pioneered by Overman (1957), Grossman (1958), Krutilla (1966), and Lind (1966) (e.g., survey on the National Flood Insurance Program by Michel-Kerjan, 2010). A prominent concern in the insurance market is moral hazard – in the case of flood insurance, flood insurance would discourage insurance adopters to invest in flood control measures. Another concern is that a large portion of individuals underestimate or are not salient to real flooding risks (e.g., Chivers and Flores, 2002; McCoy and Zhao, 2018), resulting in underinvestment of flood control facilities and overdevelopment of land. As an example of the theory of the second best (Lipsey and Lancaster, 1956), our results imply that decentralization of flood control investment can alleviate the lack of flood control investment, while decentralization of land development can aggravate the land overdevelopment.

Finally, our analysis captures the basic dynamics in the history of development along the Mississippi and Missouri Rivers (e.g., Zeckhauser, 1996; Jacobsen, 2011) and the Sacramento River (e.g., Kelly, 1989; Hanak et al., 2011). We provide more narratives in the paper.

References

Agthe, Donald E., R. Bruce Billings, and Simon Ince. 2000. Integrating market solutions into government flood control policies. *Water Resources Management* **14**: 247–256.

Beyer, Scott. 2017. Did Houston flood because of a lack of zoning? Forbes, August 30, 2017.

Brody, Samuel D., and Wesley E. Highfield. 2013. Open space protection and flood mitigation: A national study. *Land Use Policy* **32**: 89–95.

Brody, Samuel D., Wesley E. Highfield, and Jung Eun Kang. 2011. *Rising Waters: The Causes and Consequences of Flooding in the United States*. Cambridge, United Kingdom: Cambridge University Press.

Brody, Samuel D., Sammy Zahran, Wesley E. Highfield, Himanshu Grover, and Arnold Vedlitz. 2008. Identifying the impact of the built environment on flood damage in Texas. *Disasters* **32**: 1–18.

Brouwer, Roy, and Remco van Ek. 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological Economics* **50**: 1–21.

Burby, Raymond J., Scott A. Bollens, James M. Holloway, Edward J. Kaiser, David Mullan, and John R. Sheaffer. 1988. *Cities under Water: A Comparative Evaluation of Ten Cities' Efforts to Manage Floodplain Land Use*. Boulder, Colorado: University of Colorado.

Campoy, Ana, and David Yanofsky. 2017. Houston's flooding shows what happens when you ignore science and let developers run rampant. Quartz, August 29, 2017.

Chivers, James, and Nicholas E. Flores. 2002. Market failure in information: The National Flood Insurance Program. *Land Economics* **78**: 515–521.

Croghan, Lyndsey Blanche. 2013. *Economic Model for Optimal Flood Risk Transfer*. Master of Science thesis, University of California, Davis.

Dombrowsky, Ines. 2007. *Conflict, Cooperation and Institutions in International Water Management: An Economic Analysis*. Cheltenham, United Kingdom and Northampton, Massachusetts: Edward Elgar.

Eijgenraam, Carel, Ruud Brekelmans, Dick den Hertog, and Kees Roos. 2017. Optimal strategies for flood prevention. *Management Science* **63**: 1644–1656.

Eijgenraam, Carel, Jarl Kind, Carlijn Bak, Ruud Brekelmans, Dick den Hertog, Matthijs Duits, Kees Roos, Pieter Vermeer, and Wim Kuijken. 2014. Economically efficient standards to protect the Netherlands against flooding. *Interfaces* **44**: 7–21.

Foster, Kenneth R., and Robert Giegengack. 2006. Planning for a city on the brink. *On Risk and Disaster: Lessons from Hurricane Katrina* : 41–58.

Gardner, Roy, Elinor Ostrom, and James M. Walker. 1990. The nature of common-pool resource problems. *Rationality and Society* **2**: 335–358.

Ge, Quansheng, Linsheng Yang, Fengjun Jin, and Huiyi Zhu. 2017. Carrying capacity of resources and the environment of Xiong–An New Area: Evaluation, regulation, and promotion. *Bulletin of the Chinese Academy of Sciences* **32**: 1206–1215.

Grislain-Letrémy, Céline, and Sabine Lemoyne de Forges. 2015. The benefits of uniform flood insurance. *Geneva Risk and Insurance Review* **40**: 41–64.

Grossman, David A. 1958. Flood insurance: Can a feasible program be created? *Land Economics* **34**: 352–357.

Hanak, Ellen, Jay Lund, Ariel Dinar, Brian Gray, Richard Howitt, Jeffrey Mount, Peter Moyle, and Barton "Buzz" Thompson. 2011. *Managing California's Water: From Conflict to Reconciliation*. San Francisco, California: Public Policy Institute of California.

Herriges, Daniel. 2017. Houston isn't flooded because of its land use planning. Strong Towns, August 30, 2017.

Hui, Rui. 2014. *Optimal Design of Levee and Flood Control Systems*. Doctor of Philosophy dissertation, University of California, Davis.

Hui, Rui, Jay R. Lund, and Kaveh Madani. 2016. Game theory and risk-based leveed river system planning with noncooperation. *Water Resources Research* **52**: 119–134.

Intergovernmental Panel on Climate Change. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: Intergovernmental Panel on Climate Change.

Jacob, John S., Kirana Pandian, Ricardo Lopez, and Heather Biggs. 2012. *Houston-Area Freshwater Wetland Loss, 1992–2010*. College Station, Texas: Texas A&M University System.

Jacobsen, Rowan. 2011. *A Shadows on the Gulf: A Journey Through Our Last Great Wetland*. New York: Bloomsbury Publishing.

Kelly, Robert L. 1989. *Battling the Inland Sea: Floods, Public Policy, and the Sacramento Valley*. Berkeley, California: University of California Press.

Krutilla, John V. 1966. An economic approach to coping with flood damage. *Water Resources Research* **2**: 183–190.

Lind, Robert C. 1966. The nature of flood control benefits and the economics of flood protection. Technical Report No. 145, Institute for Mathematical Studies in the Social Science, Stanford University.

Lipsey, Richard G, and Kelvin Lancaster. 1956. The general theory of second best. *Review of Economic Studies* **24**: 11–32.

Lünenbürger, Benjamin. 2006. *The Economics of River Flood Management: A Challenge for the Federal Organization?* Doktors der Wirtschaftswissenschaften dissertation, Ruprecht-Karls-Universität Heidelberg.

McCoy, Shawn J., and Xiaoxi Zhao. 2018. A city under water: A geospatial analysis of storm damage, changing risk perceptions, and investment in residential housing. *Journal of the Association of Environmental and Resource Economists* **5**: 301–330.

Michel-Kerjan, Erwann O. 2010. Catastrophe economics: The National Flood Insurance Program. *Journal of Economic Perspectives* **24**: 165–186.

Overman, Edwin S. 1957. The flood peril and the Federal Flood Insurance Act of 1956. *Annals of the American Academy of Political and Social Science* **309**: 98–106.

Taylor, Michael. 1987. *The Possibility of Cooperation.* New York: Cambridge University Press.

van Dantzig, David. 1956. Economic decision problems for flood prevention. *Econometrica* **24**: 276–287.

Vigdor, Jacob. 2008. The economic aftermath of Hurricane Katrina. *Journal of Economic Perspectives* **22**: 135–154.

Wu, Qinglong, Zhijun Zhao, Li Liu, Darryl E. Granger, Hui Wang, David J. Cohen, Xiaohong Wu, Maolin Ye, Ofer Bar-Yosef, Bin Lu, Jin Zhang, Peizhen Zhang, Daoyang Yuan, Wuyun Qi, Linhai Cai, and Shibiao Bai. 2016. Outburst flood at 1920 BCE supports historicity of China's Great Flood and the Xia dynasty. *Science* **353**: 579–582.

Young, Robert A., and Robert H. Haveman. 1985. Economics of water resources: A survey. *Handbook of Natural Resource and Energy Economics* **2**: 465–529.

Zeckhauser, Richard. 1996. The economics of catastrophes. *Journal of Risk and Uncertainty* **12**: 113–140.