Cities 100 (2020) 102658

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Surging seas, rising fiscal stress: Exploring municipal fiscal vulnerability to climate change

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ARTICLE INFO

Keywords:
Fiscal stress
Land finance
Property taxes
Climate change
Sea level rise
Adaptation

ABSTRACT

Recent disasters and growing concerns about climate change have spurred calls for cities to retreat from and avoid developing in coastal areas. Instead, cities have doubled down on waterfront development. We ask why and with what implications, using the U.S. state of Massachusetts as a case study. By overlaying data on sea level rise, land use, and property taxes, we find a few coastal cities may lose significant levels of municipal revenues to long-term sea level rise, while others face negligible impacts. Coastal municipalities are cognizant of their risks yet continue to site redevelopment projects in flood-vulnerable areas to meet present-day budgetary needs. Moreover, they resist efforts to align property values and insurance premiums with climate risks, as reforms only hasten lost taxes. Left unchanged, existing land use and fiscal policies incentivize municipalities to make short-term decisions with accelerating climate risks over time. This creates new dynamics of fiscal stress that can increase regional inequality and vulnerability to climate change. The study highlights the need for dialogue among researchers and policymakers in the U.S. and internationally on the nexus between land use planning, government administration, and climate change as these tensions likely exist wherever local governments rely on land-based finance.

1. Introduction

Recent disasters and growing concerns about climate change have spurred calls for cities to retreat from and avoid development in low-lying coastal areas. Many studies in the field of climate adaptation have focused on assessing cities' infrastructure systems, the social impacts of climate change and adaptation responses, and the costs of action or inaction. However, few studies have examined how fiscal policies drive cities to develop where they do and constrain their adaptation responses. Many guidelines and adaptation plans further advocate that cities adopt land- and growth-based financing mechanisms, such as property taxes and municipal bonds, to implement adaptation projects. These strategies overlook how climate change may affect future municipal revenue streams, how such financing mechanisms incentivize increased development in flood-prone areas, and how uneven capacity to use these growth-based tools can shape intra- and inter-regional spatial inequality.

This paper sheds light on these dynamics by examining the impacts of one climate hazard (sea level rise, SLR) in one U.S. state (Massachusetts) for one aspect of local budgets (property tax revenues). We ask: which cities stand to lose the most local revenues due to SLR? What are the implications of their spatial distribution? How do current land use conditions affect cities' abilities to overcome budget gaps? To what extent has knowledge about climate impacts affected local land use planning? We focus on Massachusetts given the state's high exposure to SLR and its coastal municipalities' budgetary reliance on property taxes. The study uses a mix of geospatial and qualitative data sources and analytical methods. We examine only the effects of SLR on property taxes because of the availability of data for this type of analysis. The full fiscal impact of climate change is likely much greater when accounting for multiple hazards, broader economic impacts, and rising local service and expenditure needs.

We first review the literature on the nexus of land use planning, fiscal policy, and hazard mitigation in the United States, and explore how climate change can exacerbate fiscal stress. We then assess (1) how SLR would impact local revenues in coastal Massachusetts if no adaptive actions are taken, (2) cities' ability to compensate for this loss given land use, demographic, and fiscal constraints, and (3) how cities are currently balancing fiscal, land use, and climate considerations. We find that SLR will significantly impact a small subset of municipalities, many of which are land constrained and already fiscally stressed. These cities are currently maximizing waterfront development despite knowledge of

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https://doi.org/10.1016/j.cities.2020.102658
Received 3 October 2018; Received in revised form 27 November 2019; Accepted 15 February 2020
Available online 24 February 2020

climate risks. Even if built with resilience measures, these practices place more people and assets in areas that will become increasingly expensive to sustain. Moreover, municipalities with the most fiscal exposure due to SLR are scattered among those with lower exposure, creating an uneven landscape of municipal fiscal vulnerability along the coast. These dynamics create new sources of conflict between cities and other levels of government. Left unaddressed, climate change can contribute to new dynamics of fiscal stress, spatial inequality, and regional vulnerability.

This study suggests that the field of public administration should pay more attention to climate impacts given how it can compound traditional sources of fiscal stress. Furthermore, it suggests the field of adaptation planning should account for fiscal vulnerability and land use constraints in climate adaptation assessments. Finally, the study underscores a need to scrutinize policy frameworks that fiscalize land use in a world undergoing climate change. Although our study focuses on Massachusetts and the U.S. policy context, many other countries espouse similar land use, fiscal, and natural hazard management policies. Researchers and policymakers in the U.S. and internationally have an opportunity to compare and learn from diverse experiences as tensions between fiscal policy, land use authority, and climate change are likely relevant wherever local governments rely on land-based finance.

2. Land Use – Fiscal Policy – Climate Vulnerability Nexus

In the United States, a fragmented, complex set of policies governs disaster risk reduction and land use planning. Historically, federal and state governments have not regulated local development in environmentally sensitive areas (Burby, 1998). Instead, the federal government has invested heavily in flood mitigation infrastructure to provide protection up to a certain level of risk. It also created institutions like the Federal Emergency Management Agency (FEMA) and its National Flood Insurance Program (NFIP) to provide insurance and distribute aid for post-disaster recovery. Paradoxically, these policies have invited development into hazard-prone areas by reducing perceptions of risk and externalizing costs of damages. Many states require local governments to develop land use plans and manage coastal zones, but such requirements can have few provisions concerning natural hazards, sea level rise, or implementation (Dyckman, St. John, & London, 2014; May & Deyle, 1998). Only since 2000 has the federal government required municipalities to draft a hazard mitigation plan (HMP) in order to qualify for non-emergency federal disaster assistance. While nearly 21,000 municipalities have HMPs, the federal mandate does not require their implementation. Plan quality and implementation are mixed and municipalities routinely develop in places deemed risky in their own HMPs (Berke et al., 2015; Berke, Malecha, Yu, Lee, & Masterson, 2018; Chapin et al., 2007). Litigation over efforts to regulate private property further discourages cities from aggressive regulations (Meltz, Merriam, & Frank, 1998).

Flood risk mitigation efforts, in part, have helped to securitize investments in land improvements and therefore in property tax rolls. Across states, property taxes constitute between 10% (Arkansas) and 56% (New Hampshire) of local government revenues. Within states, this range can be even higher. For instance, although property taxes constitute 41% of local revenues in Massachusetts, they constitute on average 60% of local revenues among its coastal municipalities. As a percentage of local own source revenues (i.e., excluding transfers from state and federal governments), these numbers rise to between 21% (Alabama) and 85% (Connecticut), with coastal Massachusetts near the high end at 73% (U.S. Census Bureau, 2012). Local reliance on these forms of revenue has increased in recent decades as federal and state austerity measures have reduced their transfers to local governments (Wildasin, 2010). Devolved fiscal stress exerts even greater pressure on local governments to raise revenue by boosting assessed property values, expanding tax bases through more development, and expanding user fees and charges (Aldag, Warner, & Kim, 2019; Kim, 2017).

These policies provide cities with fiscal and political incentives to continue developing in vulnerable areas on the one hand, and limited financial flexibility or requirements to avoid such practices on the other. Although this framework has long driven development in risky places, climate change escalates tensions between land use planning and efforts to balance current budgets. The challenges are evident in the exponential increase in economic damages from climatological disasters over time, even as disaster risk management has reduced the loss of life (NOAA, 2019). The NFIP's insolvency ($20.5 billion in debt at the time of publication) and rising proportion of disaster aid in the national debt (18% of additional federal debt in 2018) are but two indicators of the disconnect between national hazard mitigation policies and fiscalization of local land use (Elis, 2018; Horn, 2019).

This structural framework constrains local aspirations for rational or forward-looking land use choices with respect to climate adaptation and hazard mitigation. In the aftermath of disasters like those wrought by Hurricanes Katrina and Harvey, pundits and publics alike decry land use decisions to pave over wetlands or build in low-lying areas, particularly where those developments are sprawling subdivisions or require massive tax dollars to rebuild. Questions of race, class, power, and inequality have dominated debates about who should benefit from flood insurance, who can move back, and who should be protected (Hersher & Benincasa, 2019). For the most part, these important debates have ignored cities' *fiscal* vulnerability to climate impacts, the underlying fiscal incentives and obligations that shape where cities build, and the need to reconsider these policies given climate change in order to address systemic drivers of “unresilient” land use practices.

3. Sea level rise as a new source of fiscal stress

Sea level rise can affect municipal budgets on both the revenue and expenditure sides. On the revenue side, SLR could fundamentally restructure local economies and erode property taxes. Climate impacts will affect employment and businesses that rely on natural resources, such as recreation, logging, paper, fisheries, and tourism, thereby impacting local and state tax revenues. Disasters cause net migration out of the area, with negative repercussions on local revenues (Boustan, Kahn, Rhode, & Yanguas, 2017). Markets are just beginning to signal awareness of climate change, with recent studies finding that homes exposed to SLR sell for 7% less than unexposed properties (Bernstein, Gustafson, & Lewis, 2019). Properties may lose more or all of their market value as they become more frequently flooded or permanently inundated (Atreya & Ferreira, 2015). Other cities, however, may reap the benefits as some municipalities suffer economic and population decline. A study of Miami-Dade County found property price appreciation is positively associated with topographic elevation, suggesting the beginnings of “climate gentrification” (Keenan, Hill, & Gumber, 2018). In administratively fragmented metropolitan areas, such changes likely take place in different cities, yielding net winners and net losers.

On the expenditure side, added local costs include: maintaining and repairing roads due to coastal storm events and rising water tables; adapting water supply and drainage systems to account for more intense storms and storm surge; and expanding community health, education, and disaster preparedness and response (Hunt & Watkiss, 2010). These operating, personnel, and capital investment costs are inflexible and shrink slowly even if residential populations decline. Federal disaster funding has increased over time (Lingle, Kousky, & Shabman, 2018), but the federal government has proposed to increase local cost-shares for disaster recovery before federal aid kicks in (Flavelle, 2017). With federal willingness to fund local disaster and recovery needs in flux, local expenditure burdens will likely increase under climate change.

Only recently has research emerged on the local fiscal impacts of climate change. Historically, climate assessments focused on economic losses caused by climate change, physical damage to the built environment, and communities' social vulnerability (Cutter, Emrich, Webb, & Morath, 2009; Füssel & Klein, 2006; IPCC, 2012; Kirshen, Knee, & Ruth, 2008; Lynn, MacKendrick, & Donoghue, 2011; Melillo, Richmond, & Yohe, 2014; Risky Business, 2014). Researchers of natural disasters similarly observe that the fiscal impact of disasters is under studied (Boustan et al., 2017; Deryugina, 2016; Miao, Hou, & Abrigo, 2018). Some studies focus more on the implications of climate change on national rather than local fiscal conditions (Ekins & Speck, 2014). One exception is a 2018 report by the Union of Concerned Scientists (UCS) that assessed for the first time national fiscal vulnerability to SLR. It found that 2.4 million properties currently contributing $12 billion in property taxes could lose their value with 6.9 ft of SLR. Under these projections, 120 municipalities would risk losing 20% or more of their current property tax base, and 30 municipalities could lose as much as 50% of their property tax base within the next 30-year mortgage cycle, thereby implicating ongoing property transactions (UCS, 2018a). These estimates – for one climate hazard to one aspect of municipal budgets – highlight the potential magnitude of climate-driven fiscal stress.

Municipalities historically have managed fiscal gaps and stresses by changing local tax policies, development incentives, and service delivery. Cities embracing "strategic management" or "pragmatic municipalism" leverage public-private partnerships, create new markets, seek out new sources of local revenues, and increase existing fees and taxes to maintain service levels (Johnston & Girth, 2012; Warner & Clifton, 2014). Under climate change, such strategies could include creating new or upgrading existing neighborhoods into resilient high-end districts. Other municipalities, especially if they have high anti-tax sentiment and/or have more tax-exempt property, adopt policies of austerity urbanism (Aldag, Kim, & Warner, 2019). This is characterized by cutting public services, stern budgetary oversight, and privatization (Peck, 2012). Such a "hollowing out" of municipal budgets commonly manifests in deferred capital investment, increased user fees, frozen salaries, layoffs, and cuts to services (Warner & Clifton, 2014).

Based on this review, we hypothesize that municipalities operating under this policy framework are likely to maximize coastal development even if they are aware of the impacts of climate change. To evaluate this, we first use spatial analysis to identify municipalities with the greatest fiscal impact due to SLR. We describe the land use, fiscal, and demographic conditions that characterize coastal municipalities given their level of fiscal vulnerability to climate change. We then ask if and how land use and development planning reflects knowledge about climate vulnerability for highly fiscally exposed municipalities that have conducted climate vulnerability assessments.

4. Case selection and methods

The state of Massachusetts (MA) serves as an extreme case for this research (Seawright & Gerring, 2008) given that its local governments have both high reliance on property taxes and high exposure to SLR. For instance, Boston likely has more man-made land than any other city in the country, with 5250 acres built on fill created by leveling nearby hills (Seasholes, 2003), a practice that neighboring cities emulated. By 2100, SLR may return Metro Boston to its geographic extent before land making projects (Douglas, Kirshen, Li, Watson, & Wormser, 2013; Seasholes, 2003). Present-day coastal floods with an annual 1% chance of being equaled or exceeded (the so-called 100-year storm) could have a 20% chance of taking place each year by 2050 and may be as frequent as daily high tide by 2100 (City of Boston, 2016).

Since 2016, the state has required all local municipalities to develop a "Municipal Vulnerability Plan", and many cities had developed assessments and plans even before the mandate. Yet, most municipalities face funding constraints in implementation. Massachusetts prohibits municipalities from raising revenues from sales, income, hotel, and meal taxes. As a result, coastal municipalities in Massachusetts have some of the highest levels of property tax reliance nationwide: an average of 60% of total revenue and 73% of own source revenue in 2012 (U.S. Census Bureau, 2012). At the same time, the state's Proposition 2½ (passed in 1980) caps the property tax municipalities may levy to 2.5% of the total assessed property value (Schuster, 2012). These factors incentivize municipalities to grow property tax bases through gentrification or development expansion, as they cannot exceed the tax cap without voter approval.

In this context, we examine local government fiscal vulnerability to SLR. Climate vulnerability is commonly defined as the product of exposure to natural hazard risks, sensitivity of people and systems to those risks, and their capacity to adapt to change due to socio-economic, institutional, technological, and political factors (IPCC, 2014). Translating this into the realm of fiscal stress, we use fiscal exposure to mean the extent to which local gross revenues are affected by the elimination of property values due to SLR. We use fiscal adaptive capacity to mean whether and how municipalities can cope with fiscal exposure.

We use spatial data analysis to assess variations in levels of fiscal exposure, then qualitatively examine how land use characteristics affect fiscal adaptive capacity to develop an overall understanding of fiscal vulnerability. The technical appendix provides a more detailed explanation of our methods. In brief, we first created a geographic information system (GIS) model that overlays the extent of SLR inundation, property tax data (at the parcel-level), and municipal fiscal data. Projections of SLR come from the National Oceanic and Atmospheric Administration (NOAA), which calculates the spatial extent of SLR based on mean higher high water (MHHW). We use NOAA data for one-foot increments of SLR between 1 and 6 ft (NOAA, 2017). Although NOAA data has its limitations, it provides a methodologically consistent map for the entire country. We overlaid this with maps from the Massachusetts Area Planning Council (Boston's regional land use planning agency, MAPC) that contain property parcels, building roofprints, and their corresponding tax and land use data (MAPC, 2018).

We draw on 2015 municipal fiscal data from the Massachusetts Division of Local Services' Municipal Databank (DLS, 2017). Fiscal health is the ability of local governments to pay for their obligations (Hendrick, 2004), but scholars hotly debate effective metrics of municipal fiscal stress (Gorina, Maher, & Joffe, 2017). The International City Manager's Association (ICMA) offers one of the most comprehensive frameworks for measuring fiscal conditions and includes 48 indicators evaluating four dimensions of solvency (Nollenberger, Groves, & Valente, 2003): cash solvency, budgetary solvency, long-term solvency, and service solvency. We include variables representing three of the four dimensions. We use cash balance as a percentage of revenues to represent cash solvency[2]; operating balance as a percentage of revenues to represent budgetary solvency; and total outstanding debt as a percentage of revenues to represent long-term solvency. We also include state aid as a percentage of revenues to assess potential impacts to local and state fiscal relations.

This comprehensive GIS model allowed us to assess where SLR maps intersected land parcels and buildings, and then calculate local taxes from land and buildings that could be impacted in one-foot increments of SLR from 0 to 6 ft. We consider only the effects of SLR on current municipal property tax revenues, not other climate impacts, the toll of climate change on municipal expenditures, or how planned or potential adaptation reduces fiscal exposure.

We then categorized municipalities by the magnitude of SLR-induced fiscal gaps at 6 ft of SLR (SLR6) and identified patterns in their land use, built form, and geography. Although we explored a cluster analysis, the qualitative categorization was simpler and produced similar outputs. For the most affected municipalities, we identified land use plans, vision

[2] Although studies have found that information about the general fund (assets and liabilities) balance, as an indicator of cash solvency, to be the most effective predictor of fiscal stress (Gorina, Maher, and Joffe, 2017), such information is not collected at the state level in Massachusetts.

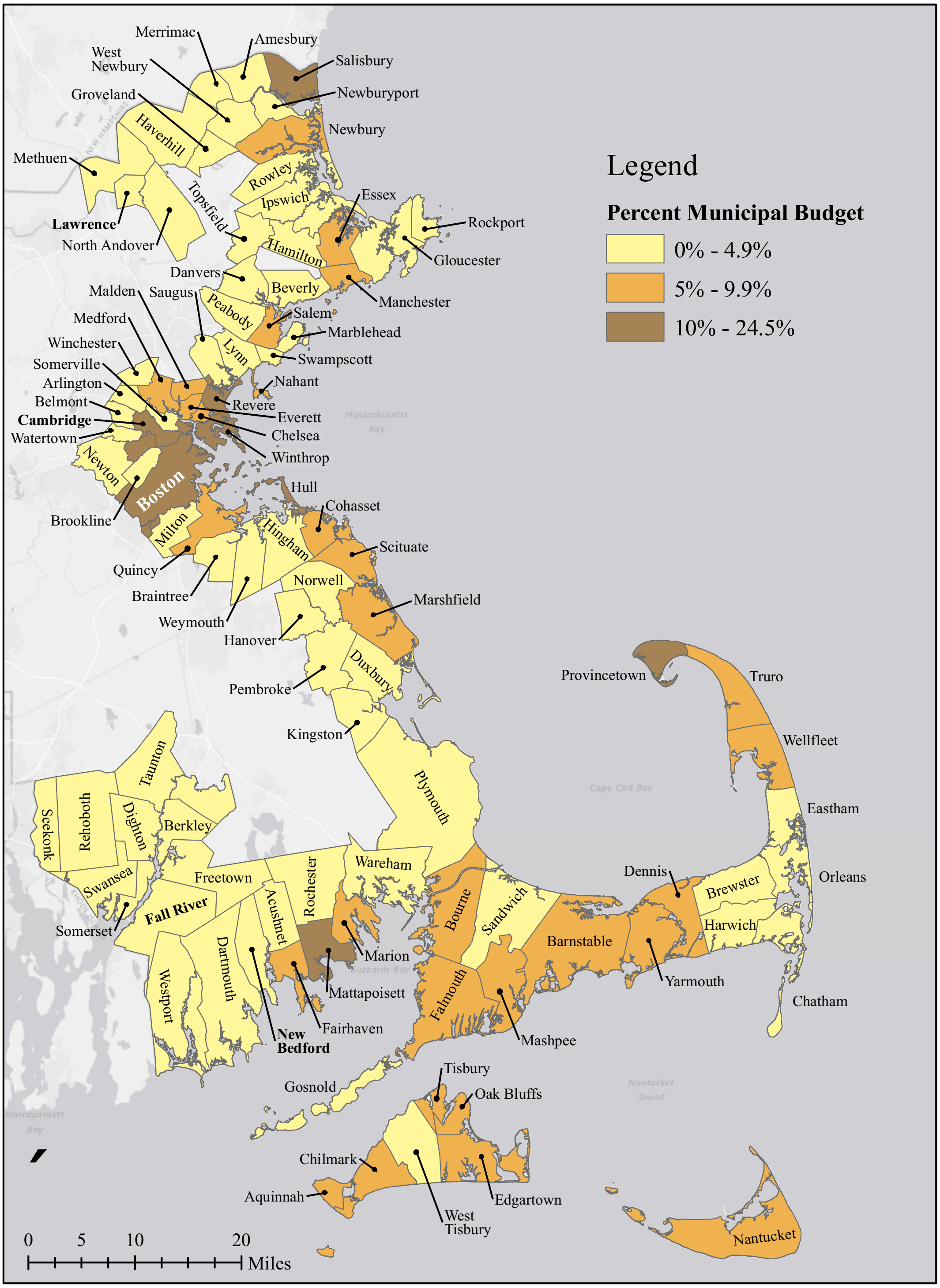

Fig. 1. Percent of total municipal revenue jeopardized at SLR6. These estimates are based on the latest available sea level rise maps from NOAA and require ground-truthing to be more reliable. See the technical appendix for a discussion of the role of dams in protecting the Cities of Boston and Cambridge from flooding.

plans, climate vulnerability assessments, and climate adaptation plans to determine the extent to which local planning reflects knowledge about SLR. This review of documents is supplemented by field research. Between 2014 and 2017, the lead author followed the Boston Metro Mayors Climate Preparedness Task Force, which involves the 14 most urbanized cities in the urban core and was created by mayors to catalyze regional climate planning. She attended their meetings and interviewed most of the staff in that group (30–60 min each), which allowed her to closely track adaptation planning in the region. The paper includes a few anonymous quotations from these interviews.

5. Impacts of sea level rise on municipalities in Massachusetts

Long-term SLR threatens significant levels of property taxes if cities do not take steps to adapt to climate change, but impacts are unevenly distributed across coastal Massachusetts, as shown in Figs. 1–3. In absolute terms, 3 ft of SLR threatens 1.4% ($104 million) of current property taxes of 89 coastal municipalities by chronically inundating over 15,000 taxable acres currently valued at $8.89 billion. Six feet of SLR threatens 12.5% ($946 million) of current property taxes of 99 coastal municipalities by chronically inundating almost 37,000 taxable

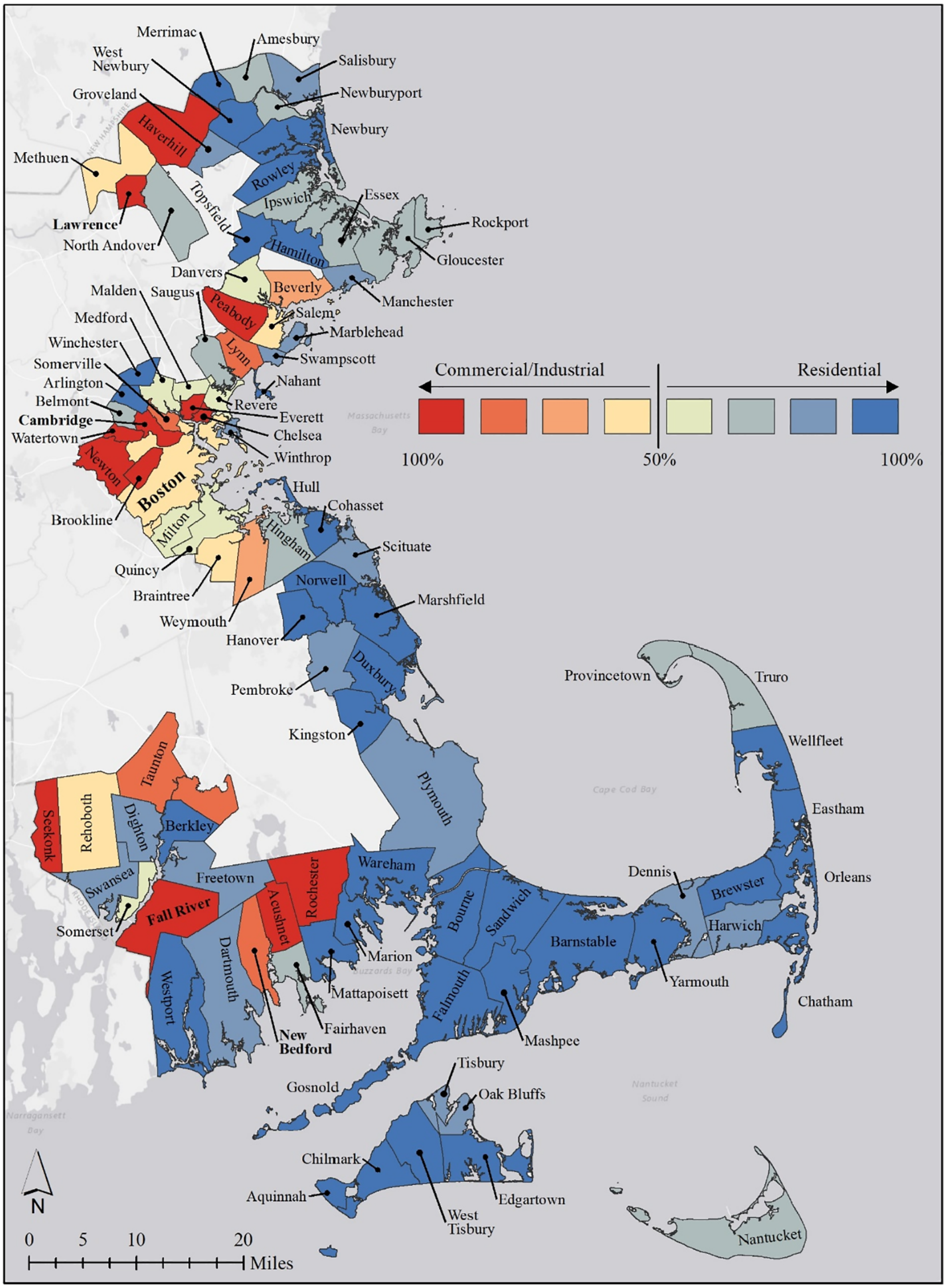

Fig. 2. Relative contribution of different land uses to property tax loss at SLR6. These estimates are based on the latest available sea level rise maps from NOAA and require ground-truthing to be more reliable. See the technical appendix for a discussion of the role of dams in protecting the Cities of Boston and Cambridge from flooding.

acres valued at $64.4 billion. Just 7 cities in Metro Boston have high fiscal exposure (defined as 10% or more of total municipal revenues at risk). Another 29 municipalities comprising a diverse set of seaside suburbs risk losing 5% to 10% of their total revenues. Most municipalities, however, face comparatively little fiscal exposure. Even at SLR6, 41 municipalities risk losing 2% or less of their total revenues and another 22 between 2% and 5%. These tend to be less urbanized communities that are inland or upland of the coast. Table 1 presents a summary of the impact of SLR6 on municipal revenues, along with descriptive statistics of the variables used in the regression analysis.

How soon these revenue losses take place depends on which climate models are used and how quickly society reduces global carbon emissions. Fig. 3 presents the revenues lost at each incremental foot of SLR, along with associated projections for when these levels of rise will take place. Tipping points appear after 4 ft of SLR when sea levels rise above or flank protective infrastructure or reclaimed land, which was filled to just above the MHHW mark (Seasholes, 2003). While $3 to $4 billion of property is flooded per foot of SLR up to 4 ft, $35 billion of property is flooded between 4 and 5 ft of SLR. This suggests that municipalities may experience low fiscal exposure for decades but face reduced

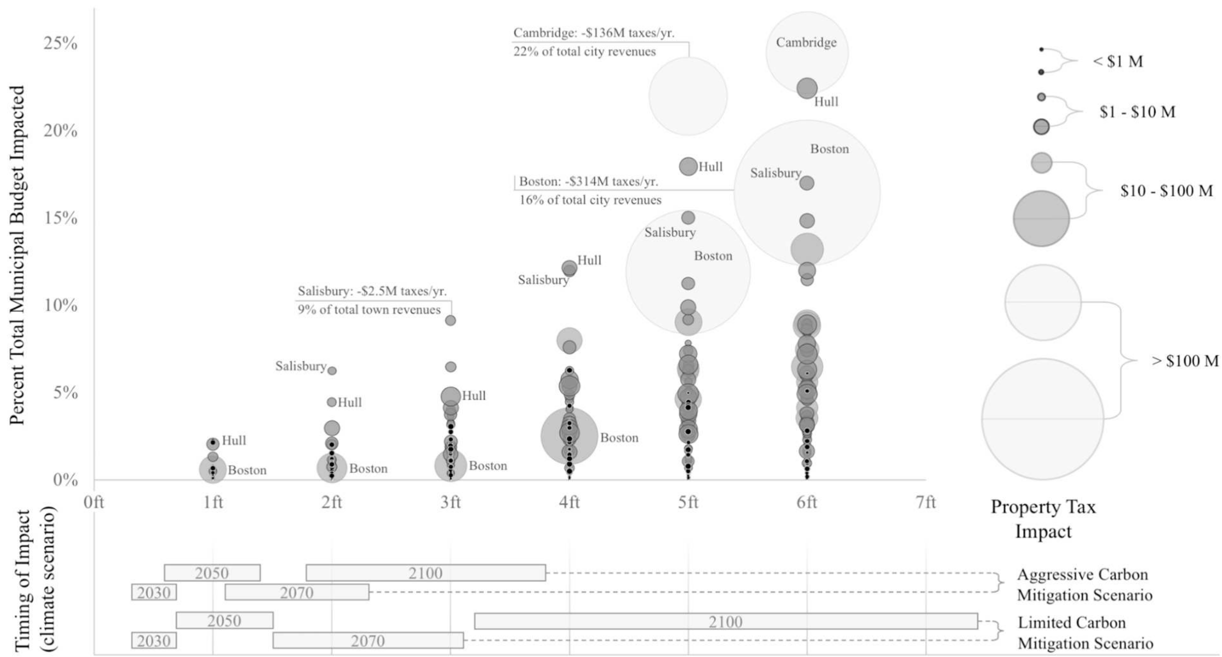

Fig. 3. Projected municipal revenue loss due to sea level rise over time.
Each bubble represents a community impacted by SLR (99 total at SLR6). Bubble size shows the magnitude of annual property taxes impacted. The y-axis shows the percentage of a municipality's gross revenues impacted by SLR. The x-axis shows the impact at one-foot increments of SLR. Projections of when sea levels rise vary depending on how aggressively societies mitigation carbon emissions (City of Boston, 2016). These estimates are based on the latest available sea level rise maps from NOAA and require ground-truthing to be more reliable. See the technical appendix for a discussion of the role of dams in protecting the Cities of Boston and Cambridge from flooding.

Table 1
Characterizing Municipalities by Levels of Fiscal Impact due to SLR6 (These three groups of cities follow the tiers of fiscal exposure almost exactly, with these modifications: we moved the inner core cities of Chelsea and Everett to Central Metro Boston because high state aid masks their exposure and moved Mattapoisett and Salisbury to Seaside Suburbs because they are more similar to those groups). Figures are based on or derived from sea level rise data produced by the National Oceanic and Atmospheric Administration (NOAA SLR Viewer, 2017); parcel, land use, and tax data from the Massachusetts Area Planning Council (MAPC, 2018); and municipal fiscal data from the Municipal Databank of the Massachusetts Division of Local Services (DLS, 2017).

N = 99	Avg	Min.	Max.	Std. dev.	Metro Boston	Seaside suburbs	Dryland retreats
Municipal socio-economic conditions							
Population (2015)	32,537	77	667,137	69,308	96,356	20,982	26,477
% Population change (2000–15)	6%	−13%	26%	8%	7%	5%	6%
Income per capita (2015)	$45,342	14,872	127,809	22,969	$36,681	$44,022	$46,897
Poverty rate (2012)	8%	0.9%	29%	5%	14%	9%	8%
Fiscal conditions (2015)							
Expenditures per capita	$3905	$2135	$22,912	$2441	$3730	$4194	$3856
State aid as % revenue	13%	0%	67%	13%	18%	9%	13%
Cash balance as % of revenue	5%	0%	31%	4%	7%	5%	5%
Operating balance as % revenue	5%	−32%	32%	7%	9%	6%	5%
Outstanding debt as a % of revenue	105%	0.05%	2015%	229%	505%	81%	72%
Built environment characteristics							
Land area (mi^2) (2018)	19.35	1.05	96.46	15.25	11.32	17.59	20.92
% Land area inundated at SLR6	13%	0%	53%	13%	37%	19%	8%
LCR of inundated areas at SLR6	0.13	0.00	0.59	0.11	0.29	0.13	0.11
FAR of inundated areas at SLR6	0.25	0.00	2.14	0.34	0.69	0.21	0.19
Fiscal impacts at SLR6 (based on 2015 fiscal conditions)							
% Total revenues impacted	4%	0%	24%	5%	15%	7%	2%
% Local OSR impacted	7%	0%	43%	8%	27%	12%	3%
Tax impact per capita	$222	$0.01	$1762	$295	$736	$433	$96

property tax revenues and rising expenditure needs within a compressed timeframe later in the century.

6. Potential land use constraints on adaptation responses

Municipalities with similar levels of revenue loss due to SLR share similarities in levels of urban development, dominant land uses, and socio-economic characteristics. We classify municipalities as the Metro Boston Core (high revenue loss, > 10%), Seaside Suburbs (medium revenue loss, 5–10%), and Dryland Retreats (low revenue loss, < 5%). The developmental conditions of these different types of municipalities provide different pressures and constraints on local government ability to overcome future climate-driven fiscal gaps. Table 1 compares the variations in spatial, socio-economic, and fiscal conditions for each group.

6.1. Metro Boston core

Property tax losses are highest in Boston and surrounding cities,[3] most of which were built at least partially on fill. At SLR6, these municipalities may lose 10% to 25% of current municipal revenues, with the two largest cities (Boston and Cambridge) comprising two-thirds of the at-risk property tax revenues statewide. These losses equal, on average, 27% of these municipalities' current own source revenues. The primary drivers of fiscal impact are expensive commercial and industrial coastal real estate. Fig. 2 shows the importance of commercial and industrial properties to revenue loss in Metro Boston compared to the rest of the state's coastline. Inundation of these land uses has an outsized fiscal impact because of these cities' split tax rate.[4] For instance, in Boston, Cambridge, Chelsea, and Everett, 30–40% of the inundated assessed property value comes from commercial or industrial properties, which account for 53–63% of these cities' property taxes.

On the whole, these highly urbanized municipalities have high existing levels of fiscal stress, shortages of undeveloped land, and intense redevelopment pressures. Table 1 shows that, of the three groups, cities in the Metro Boston Core have – on average – the lowest per capita income and per capita public expenditures, but highest levels of poverty, state aid, and operating deficits as a percentage of revenue, pointing to socio-economic vulnerability. Existing fiscal stress coupled with high rate of population growth raises pressures for local economic development to generate funding for expanded local services and investments. As some of the oldest sites of industrialization in New England, these cities are mostly built out. Additionally, except for Boston, these municipalities are only 2–6 mi^2 in land area, half of which would be inundated at SLR6. Post-industrial waterfronts offer some of the only major redevelopment opportunities in these cities. These cities have few options to compensate for revenue losses if they restrict or forgo development in low-lying areas.

6.2. Seaside suburbs

Seaside suburbs experience moderate revenue losses of 5–10% at SLR6 and are clustered in the suburbs near Boston, the islands of Martha's Vineyard and Nantucket, and pockets of Cape Cod.[5] Expensive residential properties drive most of the tax impact, as shown in Figs. 1 and 2, although affected properties range from modest working-class homes to large beachfront estates. Overall, as shown in Table 1, Seaside Suburbs have smaller populations, higher incomes, lower poverty rates, and less fiscal stress compared to Metro Boston's Core, though a few communities also have higher levels of poverty. These municipalities are larger in land area and have more inland areas available for redevelopment. Nevertheless, these towns face their own adaptation challenges. With primarily residential land uses and lower state aid, these municipalities are especially dependent on residential property taxes. But, local land use and zoning offer fewer opportunities to create large-scale new commercial or mixed-use developments to offset tax roll shortfalls from residential properties. Many suburbs already have high residential tax rates to support high per capita local government spending and will likely confront resident opposition to raising tax rates or state-mandated caps on the tax levy. Moreover, wealthy residential enclaves often resist densification or growth (Duncan & Duncan, 2004; Pendall, 1999). Some communities may have residents with the political clout to lobby for state and federal resources, but their lower population density and comparative wealth are less likely to attract significant levels of federal or state investment.

6.3. Dryland retreats

These communities experience SLR via tidal rivers but are mostly protected because they sit at higher elevations or are separated from the ocean by a band of more severely affected municipalities. Municipalities in this group may lose up to 5% of current revenues at SLR6, a comparatively lower exposure that provides Dryland Retreats with more time and opportunity to adapt. On average, these municipalities are the largest of the three types of municipalities (21 mi^2) and will lose < 10% of their land at SLR6. Inundated parcels in these communities are large lots rather than dense settlements. Generally, Dryland Retreats are less fiscally stressed, have lower rates of poverty, and have the highest income of all three groups, although a few economically distressed post-industrial cities also have low impact from SLR6. These municipalities could benefit from SLR if their higher elevations make them attractive sites for future development and have little reason to shoulder their neighbors' adaptation costs. For instance, the town manager of a town on a barrier peninsula observed, "Do any of our residents say let's protect our town so it benefits [the coastal town behind us]? I doubt it. And would any of their residents raise funds to fund our protection? I don't think so" (Philip Lemnios, Town Manager, Town of Hull, personal communication, 2019).

7. Current land use planning in the face of climate change

To what extent are these dynamics playing out on the ground? The constraints that existing land use, land availability, and fiscal stress place on adaptation planning in Metro Boston's Core cities is evident. Many of these municipalities have been proactive in assessing their vulnerability to climate change and some have developed adaptation plans. These assessments and plans show an awareness of current and future risks of flooding, storm surge, and significant levels of long-term SLR (up to 10.5 ft in Boston's climate assessment). At the same time, the biggest plans for redevelopment in the 7 municipalities most fiscally exposed to SLR are all sited on the waterfront and within SLR6. Fig. 4 maps major redevelopment projects and land use proposals for cities in Metro Boston's Core, all of which are located on land that could be chronically inundated by 2100. Table 2 compares cities' adaptation vulnerability assessment documents with their proposals of redevelopment.

The Seaport District in Boston, the largest redevelopment project in New England this millennium, was the dream of long-time Mayor Menino. Boston invested $18 billion in the Seaport District, resulting in 11.5 million square feet (MSF) of office development, in addition to nearly 3000-units of condos, 1500-plus hotel rooms, a courthouse, convention center, contemporary art museum, restaurants, and retail (Hoban, 2018). The district broke ground after decades of planning right as Boston began to research adaptation and does not account for climate change. But, since the launch of Boston's adaptation plan, the new Boston 2030 vision plan places five of six nodes of planned future development in areas currently vulnerable to flooding and predicted to be chronically inundated by 2100 (Gray, 2017). In Cambridge, the Fresh Pond-Alewife Commercial District is adding 3 MSF of housing, research, and commercial development to support the technology hub around Harvard, Massachusetts Institute of Technology, and other area universities. These areas are in the current floodplain. In Chelsea, apartment buildings with 415 units, a Federal Bureau of Investigations (FBI) building, and a transit-oriented mixed-use development are slated for the waterfront. In Revere, a 16.5 MSF development will replace a former racetrack built on filled marshland.

Perhaps the starkest example is the Town of Hull. One of the most densely settled and built out municipalities on the state's coastline, Hull

[3] Revere, Chelsea, and Everett receive 35 to 45% of their budgets from state aid. As a percentage of own source revenues, they are among the top 10 most fiscally exposed cities in the state. We include Chelsea and Everett in this category even though they may lose only 7–9% of their total revenues under SLR6.

[4] Split tax rates levy higher millage rates against commercial and industrial properties than residential properties.

[5] We include Salisbury, Mattapoisett, and Provincetown in this category because they are typologically more similar to other seaside towns. However, between 12% and 17% of their total budgets are affected because their main towns are located entirely in low-lying areas.

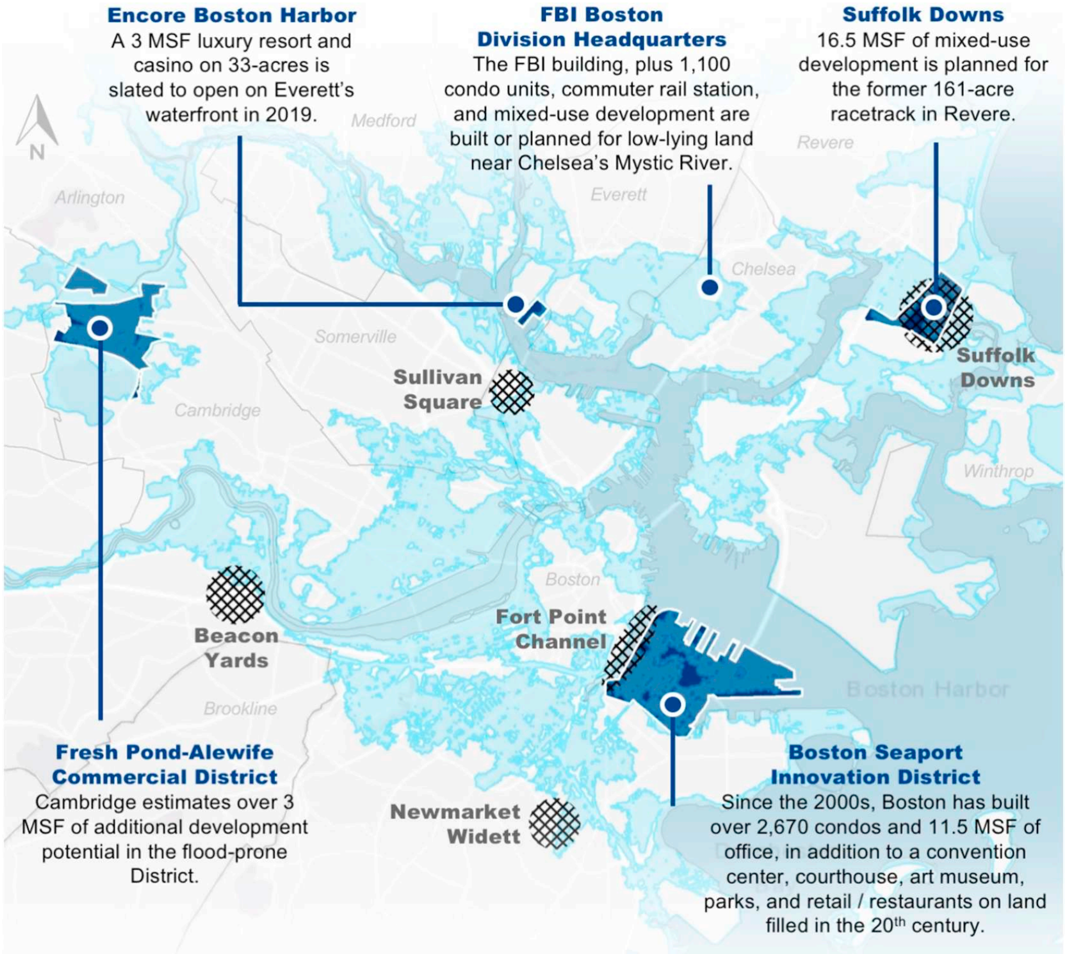

Fig. 4. Major redevelopment proposals in Metro Boston in relation to SLR6.
Hatched circles indicate proposed nodes of development in Boston 2030 vision plan (City of Boston, 2017).

has 2.8 mi^2 of land, 53% of which may be chronically inundated by 2100. Already schools let students out early at king tides to ensure they can get home before tidal flooding hits. The town has a long history of hazard mitigation and adaptation planning, has a climate-aware town manager, and has embraced a suite of recommended best practices for mitigating flood risk. Nevertheless, it is seeking to build a major beachfront tourism and hotel development on its largest remaining vacant land parcel to diversify its tax base and mitigate existing fiscal stress.

The director of planning of another small working-class city captured the tensions between resiliency and development plans (Interview, 2015):

> We're 1.8 square miles of land, built out well over 150 years ago. Our only scenario of development is redevelopment. This [flood remapping] is right in the heart of our redevelopment district, our urban renewal district.… Anything that increases the cost of our development [forces the question]: are we still going to get the economic development that's essential to keep the city sustainable? To keep the economy sustainable to pay for the services that we need today? It's not like we have 44 square miles over which to spread the development and bring in the tax revenues. We're 1.8 square miles.

To balance future adaptation and current economic development needs, communities are adopting short-term fixes to sustain continued coastal development. The cities of Boston and Chelsea have asked major redevelopments to elevate new buildings to higher base flood elevations. Cambridge is proposing additional water pumps in a dam to provide redundant infrastructure in case the dam is breached. The cities of Everett and Chelsea are proposing to build a seawall and wetlands to reduce flooding at the region's primary fresh food distribution center. Boston's resilience plan for one neighborhood proposes elevating the end of a street to block an entry point of flooding. Boston's Commissioner of Environment notes that such plans – and associated proposals to densify these neighborhoods – will reduce flooding for another 20–40 years at most, but do not resolve their long-term exposure to chronic inundation (personal communication, 2018).

Municipalities are also fighting efforts to better align property and insurance values with actual flood risks. After the passage of the Biggert-Waters Flood Insurance Reform Act in 2012, FEMA began increasing flood insurance premiums to better reflect actuarial risk and revising national Flood Insurance Rate Maps, which expanded the numbers of properties required to buy flood insurance (even without accounting for SLR). In 2013, Metro Boston municipalities like Boston, Chelsea, Revere, Winthrop, Hull, Marshfield, and Scituate appealed the new maps and won on the merits of better models of present-day flood risk. This mollified current residents and potential developers of waterfront properties. Yet, planners recognize that FEMA's revised maps will likely be correct in the long-term given climate change. Said one assistant town manager (Interview, 2015),

> I feel funny asking for a change [to flood maps] because I think in any case we need to plan for the worst case scenario, but if we don't ask for a change we're asking people who haven't have any flood infiltration into their home for 50, 60, 70, years to pay $5000 for

Table 2
Land use plans and redevelopment proposals in selected Metro Boston municipalities.

	Population in 2015	Population change 2000–2015	Land area (mi^2)	% Land flooded at SLR6	% Current revenues flooded by SLR6
Boston	667,137	13%	48.2	19%	16%
	Status of adaptation planning: Studies of SLR since early 2000s have mapped flood extents. A consortium of scientists from area universities (Boston Research Advisory Group) compiled climate science for the 2016 *Climate Ready Boston* adaptation plan. The plan recognizes the potential for as much as 10.5 ft of SLR by 2100.		Major redevelopment plans: Boston seaport district is built without climate change in mind and has already inspired design competitions to retrofit the district. *Imagine Boston 2030*, published in 2017, is the city's first comprehensive plan since 1965. Despite coming after the 2016 adaptation plan, the plan locates 5 of 6 proposed growth nodes (shown in hatched circles on Fig. 2) in flood-prone areas.		
Cambridge	110,402	9%	6.4	53%	24%
	Status of adaptation planning: 2015 *Climate Change Vulnerability Assessment* shows 20–100% probability of 3 ft of flooding in the Fresh Pond-Alewife area with a 1-in-100-year flood		Major redevelopment plans: the fresh pond-Alewife commercial district will add nearly 3 MSF of development over the next 10–15 years, including manufacturing, offices, retail, and residential properties.		
Revere	53,422	13%	5.7	51%	13%
	Status of adaptation planning: City received funding from the state in 2018 to assess its vulnerability.		Major redevelopment plans: Revere is transforming the 161-acre former Suffolk Downs thoroughbred race track (a site Boston proposed to host Amazon's HQ2) into a 16.5 MSF mixed-use development over 20 years. Phase 1 is under implementation with 1.4 MSF.		
Everett	46,050	21%	3.4	25%	9%
	Status of adaptation planning: City received funding from the state in 2018 to assess its vulnerability.		Major redevelopment plans: Encore Boston (owned by Wynn Resorts) is a resort and casino opening in 2019, built on 33 acres of land along the Mystic River.		
Chelsea	39,398	12%	2.2	39%	7%
	Status of adaptation planning: 2017 *Designing Coastal Community Infrastructure for Climate Change* report shows currently 36% of city has flood risk, rising to 42% by 2030, and 49% by 2070.		Major redevelopment plans: The city has major projects slated for its post-industrial waterfront, built on filled marshland: a new Boston FBI headquarters, 1100 units of condo apartments, mixed-use transit-oriented development, an extension of the bus line, and a commuter rail station.		
Winthrop	18,164	−1%	2.0	48%	12%
	Status of adaptation planning: 2017 *Resilient Winthrop* report shows around 30–50% of the town is likely to flood by 2070 at depth of 10 ft.		Major redevelopment plans: town master plan will redevelop areas away from the worst coastal flooding; however, the peninsular town's connections to the mainland are flood prone.		
Hull	10,491	−5%	2.8	53%	22%
	Status of adaptation planning: 2016 *Coastal Climate Change Vulnerability Assessment and Adaptation Study* shows that by 2070 61% of the town has a high probability of flooding, much of it > 10 ft deep.		Major redevelopment plans: in 2018, Hull sought proposals for a 5-acre beachfront site, the town's last remaining major vacant property, to be built as a major tourism center. The site, as it is now, has an annual 1% chance of being under 2.5–4 ft of floodwater by 2070. Although Hull rejected the proposals, its urban renewal plan for the site remains active.		

flood insurance. Is that going to change in the future? Probably, possibly.

Another director of planning observed that after the new FEMA maps came out, a "developer told me that their insurance rates would be close to $1 million.… [Developers are elevating buildings] just above the baseline flood elevation of FEMA [to avoid paying for insurance]. None of them are looking at the long-term" (Interview, 2015). This description of developers is apt for municipalities as well. Proposed new, compact, dense development in Metro Boston's urban core cities maximizes municipal tax revenue from these properties in the short-term, while increasing the volume of property and people at risk under long-term SLR.

8. Rethinking land-based fiscal policy under climate change

This study of coastal Massachusetts shows how fiscal policies and conditions contribute to both local exposure to the impacts of climate change as well as governments' capacity to adapt to rising impacts. The fiscalization of land use has driven and is driving cities to continue building on the waterfront, despite clear evidence that this is a bad idea in the long-term. In so doing, it contributes to cities' physical and therefore fiscal exposure to the impacts of climate change. Cities' fiscal stress – which derives from a range of factors, some climate-related, others not – can worsen their ability to meet growing capital infrastructure and social welfare expenditure needs. Feedback mechanisms suggest that increased expenditure needs under climate change can further compel land fiscalization to raise revenues. Under climate change, these strategies create a vicious cycle of placing ever more development in the floodplain, even as climate impacts erode infrastructure, tax revenues, and local capacity to fund services.

The dynamics seen in Massachusetts highlight the need for both policymakers and scholars to account for ecological change under land-based fiscal policy frameworks around the world. As just one form of climate change, SLR will redraw (even invert) the landscape of fiscal stress in coastal regions, with ramifications for local, regional, and state fiscal health. Areas already experiencing fiscal stress with limited alternative site for development will witness the greatest fiscal impact from SLR. Cities are building densely on their last remaining developable land in order to manage current fiscal needs despite knowledge of current and future flood risks. Many comparatively well-off municipalities may increasingly find themselves under heightened fiscal stress, while currently less developed, inland municipalities may find themselves targeted for development. Although the years 2070 and 2100 seem far off, current local and regional visioning documents are shaping development that will persist through these time horizons. Given that redevelopment opportunities and master planning initiatives arise intermittently, it is imperative for future land suitability to have greater bearing on current development planning.

Beyond local governments accounting for the fiscal impacts of climate change in future planning, our findings reveal the underlying tension between land-based local government finance and climate change adaptation that operate in many contexts. The United States relies more on property taxes (10.3% of all government tax revenue nationwide) than OECD countries (5.8%), emerging market countries (3.4%), or low-income developing countries (1.8%) (Birdsall & Gupta, 2018; El-Sibaie, 2018). However, property taxes account for a disproportionate share of local government revenues, particularly in (former) British Commonwealth countries, including the United Kingdom (15%), United States (30%), Canada (37%), Australia (38%), and New Zealand (60%) (Australian Local Government Association, 2007; Government of Canada, 2019; Government of the UK, 2017; Local Government New Zealand, 2019; Urban Institute, n.d.). Property taxes constitute the only tax local governments may collect in Australia, Ireland, and the United Kingdom (Kitchen, 2004). Local governments in China do not levy a property tax, but land-based finance (including land sales, land leases, and related taxes) accounted for 23% of local government expenditures in 2015, up from 5% in 1999 (Zhu et al., 2019). Fiscal policy frameworks where land-based revenues are a major source of own source revenues provide real incentives for local governments to maximize development. The absence of enforceable regulations on local land use planning for hazard mitigation or climate adaptation makes retreat or development avoidance in risk-prone areas that much less politically palatable.

Within the existing governance framework, low-lying cities therefore will need to compensate for tax base losses (whether due to federal buyouts, property devaluation, or disasters) by lobbying for more state aid, squeezing more money out remaining areas, or risk losing revenues, residents, and service quality. For land-constrained municipalities, this entails developing in precisely those areas that may become chronically inundated. Coastal cities with hot development markets may be able to levy new adaptation fees, raise bonds to fund adaptation, or expand development to build their tax base in a race against accelerating SLR. Commercial and industrial landowners may have resources to upgrade and protect their own properties by "turning climate risk to competitive advantage" (Anguelovski, 2015; Teicher, 2018). New high-end, "climate resilient" districts may offset property tax losses in some communities. However, such strategies problematically entrench development in low-lying areas and produce climate gentrification and ecological enclaves (Gould & Lewis, 2018; Hodson & Marvin, 2009; Keenan et al., 2018).

Municipalities in weaker markets lack such options. Local responses to current fiscal stress (for non-climate reasons) suggest climate-stressed municipalities may defer maintenance on infrastructure, cut back on services, and compete more for state and federal funding (Aldag et al., 2019). After Hurricane Harvey hit Houston, Texas in 2017, mortgage delinquency rose 200% since 80% of flooded homes did not have flood insurance.[6] Houston avoided a foreclosure crisis only because the hot housing market led developers to buy out properties that might otherwise have gone into foreclosure (Olick & Posse, 2019). Other towns with lower development pressures are already seeing homeowners abandon their homes because of flood risks, rising insurance premiums, and the inability to sell their homes, giving rise to fears of "climate slums" (Eubanks, 2016). Climate-induced fiscal stress that compound existing stresses make municipalities less able to provide basic services for remaining residents, much less fund deconstruction and ecological restoration of newly inundated areas. With Standard & Poor's, Moody's, Fitch, and Breckinridge Capital Advisors beginning to account for climate risks in municipal bond ratings (Forsgren, Chapman, Petkov, & Kernan, 2017; S&P, 2017; UCS, 2018a), growing fiscal stress may further challenge municipal borrowing and investment in adaptation.

Reformers advocate providing homeowners and homebuyers with accurate flood risk information, realigning federal disaster aid to incentivize risk reduction pre-disaster, increasing home buyouts, and improving building codes (UCS, 2018a). These changes can help individuals and markets make more informed, rational decisions about future development and are critical to preventing new development from being sited in flood prone areas. However, they do not address cities' need to balance their budgets, particularly when operating and personnel costs are less flexible than property tax rolls. Market corrections that realign property values with actual flood risks and insurance needs would accelerate the devaluation of coastal real estate, reducing property tax rolls for coastal cities and residential suburbs, and exacerbating fiscal stress in the most climate-exposed municipalities. For these reasons, local governments in Massachusetts and elsewhere have resisted reforms by appealing FEMA's new flood maps and opposing state-backed efforts to buy out homeowners after disasters like Hurricane Sandy in New York (Koslov, 2016).

Shifting dynamics of fiscal stress create new tensions between local and state governments. Local governments stressed by climate impacts

[6] Nationwide, two-thirds of properties in high risk flood areas lack insurance.

increasingly may request state aid for capital projects such as defensive coastal infrastructure, building retrofits, and supplementing basic services. For their part, states have an interest in reducing repetitive losses and having greater say in land use planning, historically a power delegated to local governments. Will states grant local governments more fiscal authority to enable them to adapt in line with mantras that "all adaptation is local" (Nalau, Preston, & Malo, 2015; Preston, Mustelin, & Maloney, 2013)? Will states require residents to contribute to adaptation funds, as MA's Governor Baker has proposed through a state excise tax on real estate transfers, or permit markets to determine which communities benefit and which decline (Keenan et al., 2018)? Will states seek to impose greater control over local land use planning as they distribute funds in order to minimize their own fiscal exposure?

In interconnected systems of infrastructure, housing, and labor markets, uneven adaptation creates weak links in regional infrastructure and contributes to cascading failures (Melillo et al., 2014; Shi, 2019). Existing regional efforts in adaptation, such as between the 14 cities participating in Boston's Metro Mayors Climate Change Preparedness Task Force, show local governments recognize their mutual interests and need for collective action. However, existing fiscal and land use planning policies that give all property tax and land use powers to local governments counteract efforts for regionally integrated adaptation. Communities with upland and less densely settled areas can accommodate future regional growth, but will anti-growth residents want such change? Would they want to help pay for their coastal neighbors' adaptation, or invite fleeing businesses and residents to settle in their own jurisdictions? New venture capital software companies like "Jupiter" facilitate such practices on a large scale by modeling the safest and most lucrative places for investors to invest (Plumer, 2018). Like the hollowing out of central cities following suburbanization, such patterns could create new pockets of socio-economic inequality, environmental injustice, and regional climate vulnerability.

Such questions underscore the temporal dimension of changing fiscal stress. Existing fiscal policies incentivize current elected officials to develop all they can, at best building new projects with modest levels of SLR in mind. Such practices contribute to even greater fiscal exposure in 2070 or 2100 for some municipalities, with compressed time frames for adaptive response given accelerating rates of SLR. Most adaptation plans call for incremental change and argue that they will adjust as better climate models and information come online. However, better climate data to date has not fundamentally changed development practices given broader structural constraints.

9. Prospects for research and policy

This study explores the impacts of one climate hazard (SLR) on one aspect of local budgets (property taxes) in one U.S. state (Massachusetts). But these patterns likely prevail for other hazards as well, such as riverine flooding, landslides, wildfires, and snow storms, and in other countries across the Global North and South. They also affect many other aspects of local budgets, such as expenditures to prepare for or adapt to climate impacts and lost economic productivity from disasters. Research synthesizing how climate change affects local revenues and expenditures across climate impacts is urgently needed. Such studies can illuminate how climate hazards cumulatively affect fiscal health across time and space.

These dynamics also point to the need to study and debate whether and how land-based fiscal policy enables effective adaptation to climate change. Studies could assess how climate-driven fiscal vulnerability compares to other vulnerabilities created by land-based fiscal policy, such as racial and school-based segregation in the United States. Such research can illuminate the tensions or opportunities for coalitions between "green" and "brown" agendas to support transformative climate adaptation. Comparisons of land use, fiscal policy, and adaptation barriers across countries also may offer new insights on polices that tackle the drivers of development in hazard prone areas.

Cities have been very open to radical, futuristic design proposals for the built environment as they explore how to adapt to climate change. This study suggests that there is a commensurate need for dialogue, research, and creativity in the areas of fiscal policy and land-based municipal finance. Connecting these disparate fields has the potential to reframe adaptation and highlight the political nature of climate adaptation as it relates to control over land use planning, fiscal policy reform, and drivers of uneven and inequitable development (Eriksen, Nightingale, & Eakin, 2015). Research and dialogue that explores the relationship between fiscal policy and climate vulnerability and that identifies opportunities to reform institutions governing land management and finance is a critical next step in transformative adaptation.

10. Technical appendix: methodology

In this appendix, we describe how we built the GIS model for the study, how it compares to the UCS 2018 study, and the limitations of our approach.

The study area is defined by the 99 municipalities impacted by 6 ft of SLR in Massachusetts. The Boston Research Advisory Group (BRAG) estimates that relative SLR of 6.5 to 18 in. (including land subsidence) is likely by 2050 and 3.2 to 7.4 ft or even 10.5 ft is likely by 2100 (City of Boston, 2016). In this paper, we were constrained to studying SLR between 0 and 6 ft because we relied on SLR spatial data the NOAA Sea Level Rise Viewer. At the time of research, this was the only SLR dataset available for the entire study area. The NOAA data's upper limit was 6 ft of SLR. We obtained the shapefiles for 1, 2, 3, 4, 5, and 6 ft of SLR for the entire MA coastline. In our paper, we focus primarily on the impacts of SLR6 as the upper limit of what current data allows us to study. Although climate projections vary, SLR6 is projected to take place eventually due to past and current carbon emissions.

We overlaid this SLR data with parcel-level tax data and municipal-level finance data. Shapefiles of tax parcels and building roofprints that are larger than 150 square feet are from the Massachusetts Area Planning Council. Tax parcel data included each lot's land use, acreage, floor-to-area ratios (FAR), lot coverage ratios (LCR), and assessed building and land values, most from within the past 3 to 5 years (MAPC, 2018). Municipal finance data is drawn from the Municipal Databank of the Massachusetts Division of Local Services (DLS, 2017). Fiscal data includes 2016 tax rates for each municipality by land use, total taxes and property taxes levied by city, and total municipal revenues and expenditures.

We intersected the spatial extents of SLR with MAPC's dataset of statewide tax parcels and roofprints to assess revenue loss at each foot of SLR.[7] We designated all parcels and roofprints as residential, commercial, industrial, or open space, and multiplied its assessed land and/or building value by that municipality's corresponding tax rate. We eliminated non-taxable parcels, special classes such as water, railroad rights-of-way, public rights-of-way, and properties with zero assessed value. We also split roofprints along tax parcel boundaries and eliminated roofprint sections that extended into extraneous parcels. Where small slivers of buildings spill onto adjacent tax parcels due to inaccuracies in the roofprint GIS data, we left them in the model as detached structures that are assigned the land use code of the parcel they overlay. Of the 955,948 parcels in the 99 municipalities, 87,330 taxable parcels lay within SLR6. Our database includes only properties of interest for tax calculation purposes.

[7] Our modeling effort takes a "bathtub" approach to imposing SLR on a static physical landscape. In reality, SLR, the gravitational weight of more water, and salinity of sea water dynamically affect coastlines through higher storm surges and tidal floods, beach erosion, stronger wave action, and conversion of salt marshes into tidal flats that not only mean the loss of habitat but also the loss of natural barriers to wave action. The Massachusetts Department of Transportation (MassDOT) is currently producing its own coastal flood risk assessment. When completed, it will dynamically model flood risk probability under a variety of SLR scenarios for the entire state.

In modeling the impacts of SLR on local property tax revenue, we assume that land and building values depreciate separately. Rising water on land will not necessarily eliminate the entire property's value. For example, many coastal properties are large estates with expansive frontage sloping up from the water. Inundation of part of that frontage would not eliminate the entire value of the property, especially if the primary structure is not impacted. Therefore, we calculate the *land value* impact based on the percentage of the parcel area inundated. When seawater touches a building, we count the entire *building value* as being "impacted". Where more than one building stood on a parcel, the building value recorded for that lot was distributed to each structure based on the percentage of the total roofprint area on that parcel. This is an imperfect approach given that the data did not indicate the number of stories of each roofprint. We iterated this step six times to model tax impacts at each foot of SLR.

10.1. Study limitations

Our data and analytical methods have important assumptions and limitations. First, like other vulnerability assessments, we compare current levels of population and development against future SLR. The models do not consider how society changes or adapts to climate change. Second, we do not account for local property tax exemptions for owner-occupied properties, which may overestimate the revenue loss in our study. Third, our analysis does not account for property depreciation or appreciation of properties near flooded zones, whether they become beachfront properties or are left as inaccessible islands.

Finally, the NOAA maps themselves have limitations as they do not necessarily accurately reflect the existence of coastal protective infrastructure, such as dams and seawalls. For a state-level study, it is impossible to collect downscaled and ground-truthed data. Given the scale of impact of the Charles River and Amelia Earhart Dams in Metro Boston, we did look into their specific vulnerability. According to the 2017 City of Cambridge Climate Vulnerability Assessment (Part 2), the Charles River Dam has a low probability (1 to 5%) of being flanked by 2055, and being overtopped by 2070, by storm surge coupled with SLR under high NOAA projections. It would be flanked before it is overtopped. Cambridge is more vulnerable from the Amelia Earhart Dam, which has a 10 to 20% probability of flooding through overtopping or flanking by 2070. The Charles River basin has low-gradient pipes that are susceptible to the river's level. Propagated flooding (backed up drainage systems) worsens surface flooding. For Boston and Cambridge, the NOAA maps roughly approximate these cities' more detailed studies.

10.2. Comparison to the UCS report

We developed our model independently and at the same time as the Union of Concerned Scientists' report (UCS, 2018a). Our approaches differ in key aspects. First, UCS also uses NOAA SLR Viewer, but reports using SLR of 6.9 ft. We were only able to obtain maps that showed up to SLR of 6 ft. Second, UCS uses tidal flooding that designates land as "at risk" if it is flooded 26 times a year (UCS, 2018b). Our approach sets a more conservative bar of permanent inundation (i.e., flooded 365 times per year) given that we are interested in conditions when the entire taxable value may be lost, rather than reduced. Third, UCS uses Zillow's ZTRAX database, which provides actual tax payments by residential and commercial properties. They default to multiplying tax rates against property values where Zillow information is unavailable. This can be a more accurate source of data due to the property tax exemptions that many cities, including Cambridge and Boston, provide to owner-occupied residences. However, the ZTRAX database excludes industrial properties, which can be an important land use group to historic industrial cities on the Massachusetts coastline. The ZTRAX data also does necessarily provide accurate geospatial location. The UCS study intersects parcel centroids with maps of SLR because ZTRAX data did not include building footprints. The MA data we obtain included building footprints. We therefore separately assessed building and parcel impacts from SLR. These differences likely explain the variations in the outcome between UCS estimates of fiscal impact in Massachusetts ($413 million) and ours ($946 million). The differences are clearest for the City of Boston, for which we find SLR6 impacts 16% of Boston's gross revenues and UCS finds 3%. More detailed comparisons are needed to determine where and why differences occur.

CRediT authorship contribution statement

Linda Shi:Conceptualization, Investigation, Writing - review & editing.**Andrew Varuzzo**:Methodology, Investigation, Formal analysis, Writing - original draft.

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