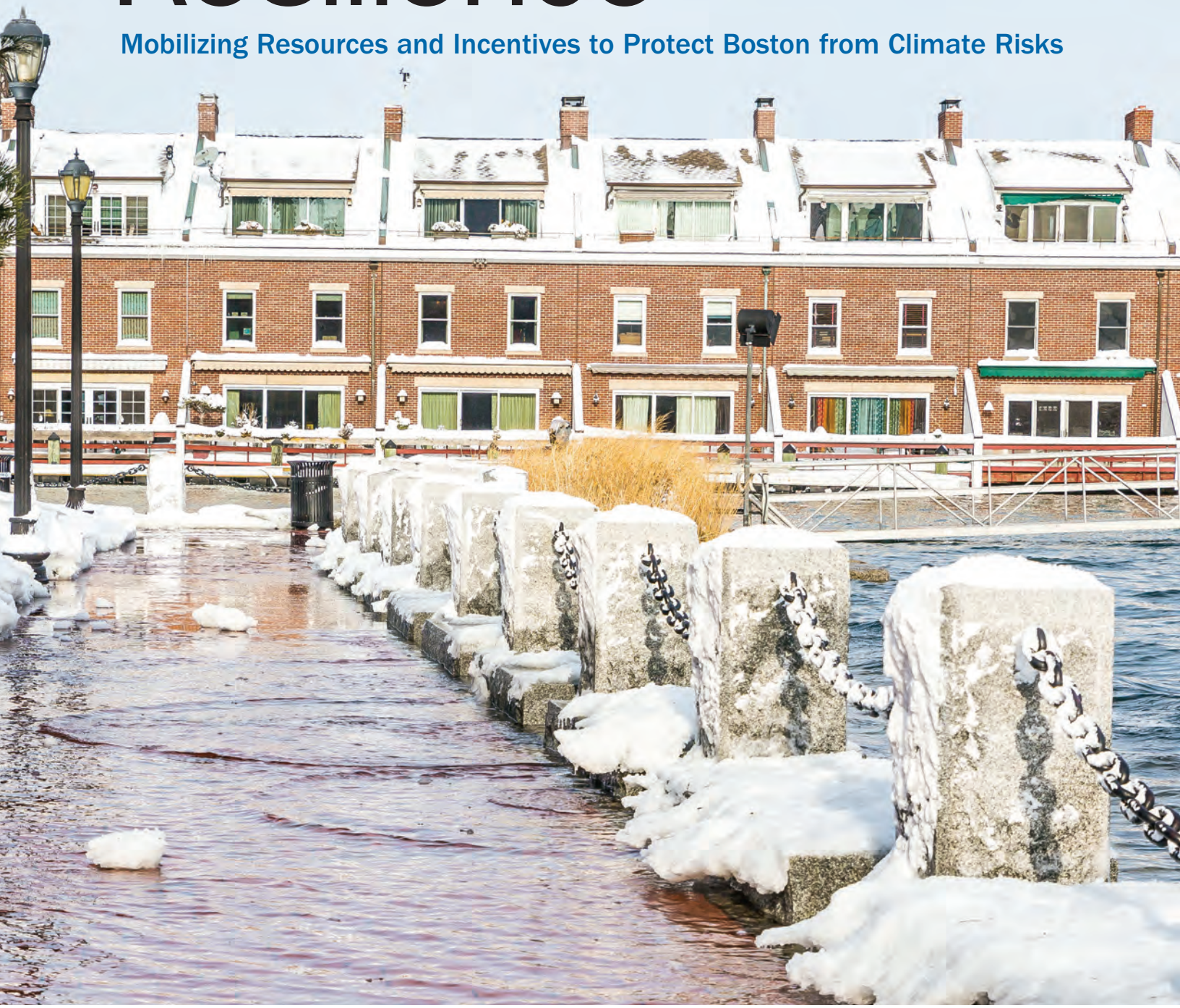
Financing Climate Resilience

Mobilizing Resources and Incentives to Protect Boston from Climate Risks



UMASS BOSTON Sustainable Solutions Lab

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Sustainable Solutions Lab

The Sustainable Solutions Lab (SSL) is an interdisciplinary partnership among four schools within UMass Boston: The College of Liberal Arts, College of Management, McCormack Graduate School of Policy and Global Studies, and School for the Environment. SSL's mission is to work as an engine of research and action to ensure that all residents of Greater Boston, and cities across the world, are prepared equitably for the impacts of climate change.

UMass Boston

The University of Massachusetts Boston is a public research university with a dynamic culture of teaching and learning, and a special commitment to urban and global engagement. Our vibrant, multicultural educational environment encourages our broadly diverse campus community to thrive and succeed. Our distinguished scholarship, dedicated teaching, and engaged public service are mutually reinforcing, creating new knowledge while serving the public good of our city, our commonwealth, our nation and our world.

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Flooding at the MBTA Aquarium Station in downtown Boston. March 2018.

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1 Introduction

WHY WE NEED ACTION

The Boston region faces very real risks of substantial damage from storm surge, extreme precipitation, and sea level rise. In 2017, weather-related disasters caused $306 billion in damages across the US as estimated by National Oceanic and Atmospheric Administration (NOAA), 40% more than the previous record set in 2005.[1] If one of the major 2017 hurricanes in the North Atlantic had hit Boston during a high tide, there could have been widespread damage costing tens of billions of dollars. Indeed, in early 2018, parts of Boston were flooded by two winter storms that produced storm surge of nearly 3 feet. The storm surge, together with the astronomical high tides, resulted in close to a 1% annual chance flood based on historical data. These major storms can disrupt power, transportation, communications, and supply chains, leading to lengthy recovery times and long-term economic impacts for residents

Flooding on Morrissey Blvd in Dorchester, Boston. March 2018.

and businesses. In fact, FEMA data indicate that about 40% of small businesses never open their doors after a disaster, and another 25% fail within a year.[2]

Proactive investments in flood protection at a range of scales are needed to mitigate these economic losses, reduce loss of life, and enhance the resilience of vulnerable communities. These investments range from measures to protect individual homes and commercial buildings, to neighborhood or "district-scale" flood mitigation projects, to multi-billion dollar schemes for regional coastal flood protection. However, a systematic approach to fund or incentivize pre-disaster resilience at these various scales does not exist.

Boston's post-Great Recession development boom, much of which has focused on low-lying areas of the city near the coast, has only increased the risks to the city. This at-risk development illustrates the limitations of climate preparedness in the absence of a coordinated, integrated approach to planning and development. Without regulatory requirements such as updated zoning and building codes, adequate finance from public or private sources and clear market incentives, climate resilience is elusive.

The City of Boston has recognized the challenges of meeting the goals of sustainable growth and development laid out in Imagine Boston 2030, while also enhancing the resilience of the region in the face of climate risks.[3] The Climate Ready Boston (CRB) initiatives have identified these risks, the potential impacts, and important strategies to advance resilience. This project aims to build on the work that has been done. While not a City of Boston report,[4] we hope to further the conversation about how the region might prepare for the impacts of climate change.

Finance is key to implementing climate resilience projects at every level because these investments may require substantial up-front costs and only generate benefits over many years. These costs are likely to be well beyond the usual capital budgets of cities and towns. In general, large-scale federal funding in the United States is mostly available post-disaster, even though in many cases it makes sense in economic, social and environmental terms to invest in resilience before disasters strike. A 2018 study by the National Institute of Building Sciences found that every $1 spent on hazard mitigation by federal agencies yields $6 in total benefits, including property damage, loss of business, and health impacts.[5]

Finance is key to implementing climate resilience projects at every level because these investments may require substantial up-front costs and only generate benefits over many years.

Resilience projects, however, face various kinds of market failures that distort incentives. This prevents property owners, government decision makers and potential investors from seeing the full range of costs and benefits. These investments face several major hurdles that can weaken the business case and make financing difficult: first, resilience projects reduce future damage, but do not necessarily generate cash flows that could service new bonds; second, resilience projects will frequently entail investments by public agencies, but the benefits largely accrue to private property owners; third, estimates of the extent and probability of future damage are very uncertain; and fourth, market signals in insurance and property markets are not yet fully reflecting climate risks. As a result, the win-win opportunities associated with energy efficiency and clean energy projects are likely to be more elusive for climate adaptation. Enhancing climate resilience will therefore require creative public policy interventions in collaboration with private sector initiatives to overcome these hurdles.

When faced with local funding constraints, cities often look to higher levels of government for help. However, in an era of constrained public budgets, we will need to develop funding sources at multiple levels. This should include private capital, leveraging market incentives, resilience metrics and disclosure, innovative design and planning and collaborative governance. Attracting private capital to large-scale climate resilience projects is difficult, however, because they do not generate significant cash flows, unlike roads and bridges that produce toll revenues, or energy efficiency investments that create predictable cost savings. Moreover, states and municipalities can issue very low cost debt, often tax free, while private capital demands rates of return around three or four times higher than the rates available to public agencies.

The Climate Ready Boston initiative is galvanizing stakeholders to take action, as they realize that the future growth and prosperity of the region demand that sound investments be made to enhance resilience and reduce the risk of major disruptions to the economy and dislocation for vulnerable communities.

Recent flood events in Boston, Houston, Florida and Puerto Rico have raised public awareness of climate risks and the need for solutions among key decisionmakers and stakeholders, including property developers and owners, businesses and homeowners, insurance and financial companies, local community groups, and city and state agencies. The Climate Ready Boston initiative is galvanizing stakeholders to take action, as they realize that the future growth and prosperity of the region demand that sound investments be made to enhance resilience and reduce the risk of major disruptions to the economy and dislocation for vulnerable communities. Moving forward will require political will, courageous leadership, and closer collaboration with local communities and business to develop the regulatory and market frameworks needed to address this challenge and ensure the future sustainability and wellbeing of the region.

This report examines various mechanisms for resilience finance and aligning incentives at multiple scales, from individual buildings to neighborhood projects to regional infrastructure. The report addresses equity and fairness concerns, and focuses on pre-disaster resilience investments rather than finance for post-disaster recovery and reconstruction. In the following sections, the report examines the growing need for resilience investments, describes various market failures, and discusses a series of mechanisms to improve resilience finance and market incentives. The report analyzes the return on investment from various resilience investments. Finally, the report offers some conclusions and recommendations.

Fairness and Equity in Resilience Finance

Climate change is likely to have disproportionate impacts on vulnerable communities and to exacerbate existing inequalities. The 2017 Resilient Boston report describes the many ways in which climate change intersects with racial and economic inequality.[6] Low income groups and communities of color tend to have lower rates of insurance and fewer resources to deal with disasters, less resilient housing, fewer options for evacuation and relocation, and poorer access to healthcare.[7] They also tend to be marginalized in decisionmaking processes. Climate adaptation investments could potentially exacerbate these problems, for example, by stimulating redevelopment patterns that increase property prices and catalyze displacement.

Climate adaptation also offers a unique opportunity to channel investments in ways that interrupt persistent inequities and target local economic development, community

Climate change is likely to have disproportionate impacts on vulnerable communities and to exacerbate existing inequalities.

inclusion, improved housing and infrastructure, and access to employment, transportation, and healthcare. Other cities, such as Portland, Oregon, have taken a lead on prioritizing the needs of underserved communities. They are developing governance structures and accountability metrics to ensure community participation and to track progress in linking climate resilience plans to equity.[8]

The type of financing has important implications for fairness and equity. Fairness means that the cost burden broadly reflects benefits provided. Equity means that the cost burden reflects ability to pay, and that resilience projects do not exacerbate inequalities. These two goals are often in tension.

SHARING THE COSTS—NARROW OR BROAD?

The costs of resilience investments can be borne by a single property owner at the parcel level, shared by those directly affected in a designated district, or spread more broadly at the city or state level.

Funding mechanisms that spread out the burden over a larger population will reduce the costs per household and avoid imposing a heavy burden on low-income families. A state-wide carbon tax or general obligation bond, for example, would share the cost of resilience investments very broadly. However, spreading the costs equally and broadly might not be viewed as fair, because some benefit more directly than others from flood protection or other measures.

A district-level scheme, such as a special assessment, imposes the costs more narrowly on those who benefit directly. However, this leads to much higher costs for the property owners in the district, and could place an undue burden on low-income neighborhoods. The benefits of resilience are likely to extend beyond the district as well. For example, protecting key infrastructure in East Boston, such as the airport, MBTA stations, and central artery tunnels, enhances the resilience of the city and the wider region. Similarly, individual parcels and buildings can be

Street flooding at Neponset Circle in Dorchester, Boston. March 2018.

integrated into resilient design for waterfront neighborhoods.

TYPE OF FUNDING—TAXES, FEES, AND PRIVATE INVESTMENT

When property taxes are the basis for resilience investments, at the city or district level, the amount paid is roughly proportional to the assessed value of property, ensuring a degree of equity. The differential between commercial and residential rates, as well as homeowner exemptions, also contribute toward equity.

However, a substantial proportion of property in the region—about 30% in Boston—is not subject to property tax, because of exemptions for non-profits that cover many colleges, churches, and healthcare facilities. Public buildings, such as schools and libraries, and public and private infrastructure, such as roads and utilities, also benefit from resilience investments, but do not pay property taxes.

A state-wide carbon tax could generate incremental revenue to support state bonds. This would spread the burden broadly, while also tying the costs to carbon emissions, the ultimate cause of climate risks. The tax could be designed to address fairness and equity concerns, depending on how the tax is collected and how the funds are used or recycled through lower income taxes.

Resilience fees could potentially be designed to address equity and fairness concerns. Water and sewer fees provide a useful basis, because everybody pays and the fees are related to the scale of a building or facility. Some municipalities are piloting stormwater fees that are tied to the area of impervious surfaces that generate runoff, which also provides an incentive for property owners to invest in reducing runoff.

Resilience fees could be calculated based on the degree of protection afforded, for example, by estimating the reduced risk of property damage. A reduction in insurance costs, actual or imputed, could provide a valuation for this. While this method directly ties costs to benefits, meeting the fairness test, it could prove complex and costly to administer. It might also raise equity concerns for high-risk low-income neighborhoods.

Hybrid financing can include multiple elements to provide a balance of fairness, equity, and to ensure sufficient scale. San Francisco, for example, is planning to finance its $500 million resilience investment with a combination of a city-wide general obligation bond and a more targeted district-level Community Facilities District that will impose a special tax on waterfront properties.

2 Climate Resilience Finance Needs

There is a broad range of needs for climate resilience funding. Examples include: the type of investment, projects at different scales, and range of time periods.

Climate resilience investments can be categorized in three broad types, according to the purpose of the investment:

1. Reduce Physical Risk

These investments are designed to protect people and property from climate impacts such as sea level rise, coastal flooding, extreme storms, and extreme heat. They typically involve investments in physical assets such as storm surge barriers, resilient buildings and infrastructure, and green infrastructure.

2. Reduce Social Vulnerability

These investments do not directly prevent physical impacts, but enhance services and support to individuals and communities that help reduce social vulnerability to climate impacts. Examples include improved responses to climate-related public health impacts; measures to protect the affordability of housing as resilience investments improve the desirability of neighborhoods; measures to protect wages and employment for employees and small businesses.

3. Increase Capacity for Emergency Response and Disaster Recovery

This entails investments pre-disaster, for example, to improve the reliability and ensure the continuity of essential services, government agencies, and key businesses, through enhanced preparedness, communications, etc. It also entails financial preparation for post-disaster spending on emergency response and recovery, for example, through insurance or catastrophe bonds.

Climate resilience investments can be categorized in three broad types, according to the purpose of the investment: reduce physical risk; reduce social vulnerability; and increase capacity for emergency response and disaster recovery.

Reducing physical exposures is the primary focus of this report. These resilience investments can also be classified by scale and ownership of (or primary responsibility for) the property to be protected. The scale of likely costs has important implications for the type of financing needed—Table 1 shows the order of magnitude of costs per building, neighborhood, and project. The ownership of the property does not necessarily mean full financial responsibility—individuals and some businesses will need some financial assistance for resilience investments, and public investments will require contributions from private capital sources and property owners who benefit.

Even if the district-level investments are carried out, robust resilience requires a layered strategy with secondary lines of defense, and some properties will be outside protected areas.

TABLE 1

Scale of Investments

	Individuals	Corporate	Public
Individual Buildings—Residential	$10–100 thousand		
Buildings/parcel—Commercial*		$0.1–8 million	
District-level projects		$40–1500 million (per district)	
Region-level (e.g. Harbor Barrier)			$7–15 billion

* Including commercial multi-family residential.

Note: These are very rough estimates based on scenarios derived from interviews, draft reports, and comparable projects in other cities.

TABLE 2

Estimates of Costs by District

	$ Million		
	2018–2025	2026–2030	2030–2050
East Boston	$43–$69	$28–$46	$46–$77
Charlestown	$16–$30	$14–$26	$3–$6
South Boston	TBD	TBD	TBD
Downtown	TBD	TBD	TBD

Source: City of Boston, Coastal Resilience Solutions for East Boston and Charlestown, 2017

TABLE 3

Boston Buildings Exposed to Frequent Stormwater Flooding

	2030s–2050s	2060s–2090s	2070s–2100
No. Buildings	8,970	9,610	11,230
Residential	68%	68%	68%
Commercial/Other	32%	32%	32%

Source: City of Boston, Climate Ready Boston, 2016

Recent district-level studies have examined the cost of projects to address climate risks.[9]

The neighborhood studies have not been completed yet, so total figures cannot yet be estimated with any confidence. We propose, as an illustrative scenario rather than an estimate, that the total cost of near to mid-term district-level adaptation measures in Boston could be between $1–$2.4 billion.[10]

Considerable investments will also be needed to enhance resilience for individual buildings, or city parcels. Even if the district-level investments are carried out, robust resilience requires a layered strategy with secondary lines of defense. Plus, some properties will be outside protected areas. Most of these investments will be undertaken by individual building owners, such as homeowners, commercial property owners, and government agencies. Disruption is minimized and recovery accelerated by enabling most of the population to shelter in place and in facilitating continuity of businesses and government services. However, the cost of these retrofits and distorted incentives facing property owners could present a hurdle to making needed investments. As with energy efficiency retrofits, there is room for programs that provide assistance with resilience audits and any improvements needed.

The cost of retrofits for increased resilience is difficult to estimate because there is very limited experience or data available. The CRB 2016 report provides data on the number of buildings exposed to frequent stormwater flooding in Boston. Table 1 provides coarse estimates of the cost of building resilience retrofits, but we cannot estimate the total cost for Boston without more specific data.

A harbor-wide barrier to protect Boston and other towns from major storm surge is the subject of an ongoing study, expected to be released in spring 2018. The report examines the feasibility and cost of such a barrier, stretching from Winthrop to Hull with gates to allow shipping but that could close occasionally. The cost of such a barrier is

expected to be in the $7–$15 billion dollar range, although experience with similar major infrastructure projects suggests that actual costs often run much higher than forecasts.

It is important to note that a harbor barrier would not obviate the need for neighborhood or building level investments. A project of this scale would take several decades to plan, design, permit, and finance; it is unlikely it would be deployed before 2050. Substantial investments would be needed regardless over the next 30 years. Moreover, a gated barrier would protect against storm surge but not tidal flooding, which would become more frequent in the second half of the century with sea level rise. This is because the movable section of the barrier could take several hours to open and close, and would not be designed for frequent operation. A barrier can also fail, requiring multiple layers of defense.

It is important to note that a harbor barrier would not obviate the need for neighborhood or building level investments. A project of this scale would take several decades to plan, design, permit, and finance, and it would be unlikely to be deployed before 2050.

Flooding of the Harbor Walk in Dorchester, Boston. March 2018.

3 Climate Resilience Finance Challenges

THE ROLE OF MARKET FAILURES

Markets work well when decision-makers—whether private developers, banks and insurance companies, building owners, or public officials—have adequate information and face incentives to make appropriate decisions that serve the long-term interests, not just of private investors, but of society as a whole. The right incentives and price signals would ensure that resilience projects are undertaken when the overall benefits of these projects outweigh the costs. Climate resilience investments, however, are beset by multiple market failures that distort incentives and make it difficult to raise the funding needed for these projects. Addressing these market failures is not a simple task and requires thoughtful policy measures.

The key sources of market failure for climate resilience financing and investment are:

- Inadequate information on costs and benefits
- Incorrect pricing of risk
- Collective action challenges
- Capital budget constraints
- Misaligned incentives

The section below elaborates on market failures—the following section on financial mechanisms then discusses how some of these challenges might be addressed.

Inadequate Information on Costs and Benefits

A key market failure is the range of uncertainty regarding the severity and timing of future climate impacts, the consequent damage, and the extent to which various resilience measures might reduce the damage. One of the central benefits of Climate Ready Boston was its development of a credible consensus on climate projections to be used (and regularly updated) by regulators, developers and investors. Nevertheless, the science is still evolving regarding the rate of sea level rise and changes in storm patterns and precipitation. Importantly, the biggest unknown is how effectively we are able to reduce emissions globally; this factor will have the biggest impact on how dramatic sea level rise is. Boston's development trajectory is also difficult to forecast over the course of several decades. Boston's Seaport, South Boston and East Boston neighborhoods, for example, have experienced explosive development and real estate appreciation since the end of the Great Recession in 2011.

The existing models used by insurers and others tend to underestimate the amount of damage caused by extreme storms. Superstorm Sandy, for example, caused a systemic collapse in New York's transportation, power, and communications infrastructure, extending recovery times and disrupting business and essential services for much longer than expected. Hurricanes Irma and Maria have

Damage to Haiti as a result of Hurricane Sandy. October 2012.

set back the economies of Puerto Rico and other Caribbean Islands, potentially for years. The depth-damage functions used by insurance companies to predict building-level losses do not capture these larger-scale cascading disruptions, and business interruption losses are usually estimated very coarsely. Losses to infrastructure are often underestimated because these assets are typically underinsured and hard to value accurately in models.

Finally, it is difficult to estimate the value of protection afforded by various resilience investments in the face of climate change, because projects tend to be idiosyncratic and we do not have much experience with new approaches such as green infrastructure. Some of the benefits are social, environmental, or related to public health, and therefore hard to quantify and monetize—for example, a greater sense of security and community, or the prevention of pollution from flooded chemical sites.[11]

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INCORRECT PRICING OF RISK

The price of risk is a key factor driving resilience investments, just as the price of carbon is crucial for driving investments that reduce carbon emissions.[12] If insurance costs accurately reflect the rising risks from climate impacts, they provide appropriate incentives to invest in flood resilience or move to less flood-prone areas. However, insurance premiums do not currently adequately price risk, for several reasons. The National Flood Insurance Program (NFIP) administered by FEMA underprices risk as a matter of policy, to make it affordable. This creates what the insurance industry calls "moral hazard," meaning that property owners are encouraged to undertake risky behavior. Federal flood insurance is "subsidized floodplain

development," said Phil Bedient, an engineer at Rice University.[13]

The FEMA 1% annual chance flood maps can also be misleading, as they are based on historical data and do not account for future sea-level rise likely to occur during the useful life of buildings. More than half of the damage caused by the Louisiana floods in August 2016, for instance, was outside the FEMA 100-year flood zone. Many state insurance commissions expressly prohibit risk-adjusted premiums in order to shield risky properties from high premiums, effectively subsidizing them. Federal disaster aid can also deter resilience investments by private and public actors. The 1988 Stafford Act commits the federal government to provide 75% of the cost of rebuilding damaged roads, bridges and other infrastructure once the President declares a federal disaster area.

Private insurers typically set rates to reflect historical data rather than future projections, and insurance companies are not always fully aware of the rising risks or face market pressures to keep rates low. When insurers are unable to price risk accurately, or to charge enough to fully cover risks, they sometimes withdraw from markets altogether.

Although the insurance industry and FEMA are beginning to examine risk-based pricing models (discussed further below in section on financing and incentive mechanisms), progress appears to be slow. Limited anecdotal evidence indicates that individual building owners find it difficult to negotiate meaningful discounts with insurers in return for resilience investments. Private insurers typically set rates to reflect historical data rather than future projections, and insurance companies are not always fully aware of the rising risks or face market pressures to keep rates low. In any event, insurance is usually purchased and priced on an annual basis, so buyers are unlikely to anticipate sharply rising insurance costs. When insurers are unable to price risk accurately, or to charge enough to fully cover risks, they sometimes withdraw from markets altogether, as has been reported in areas of coastal Florida or in California as a result of wildfire risk.

Similarly, real estate prices do not yet fully reflect climate-related risks. This reduces the incentive for owners to invest in resilience, and encourages developers to over-build in risky areas. Sellers have little reason to disclose risks, and there are not yet generally accepted standards or disclosures to help inform buyers. Without effective flood resilience strategies, cities such as Boston, New York, Miami and Houston risk creating waterfront real estate (and property tax) bubbles that could suddenly collapse if repeated flooding triggers contagious fear of losses.[14]

Finally, climate risk is not yet adequately factored into the interest rates that businesses, homeowners, or governmental agencies pay on mortgages or debt financing. If this aspect of risk were priced appropriately, it would also provide an incentive for investments in resilience.

COLLECTIVE ACTION CHALLENGES

Even if everyone in the region agrees that resilience measures are needed, there are governance and finance hurdles to effective collective action, particularly in the US context of fragmented authority. Government agencies usually try to solve collective action problems by raising taxes and fees to invest in projects that serve the public interest. Many resilience projects, such as harbor barriers, storm-water management, public transit and utilities upgrades require new funding sources, regulatory action and approval, involving multiple agencies, municipalities, and businesses. Conflicts can arise as parties recognize their differential exposure to costs and benefits from various proposed projects, responsibilities for implementation, and constraints on their authority.

Cities such as Copenhagen, Amsterdam, Hamburg, and Singapore that are effectively engaged in climate preparedness have more centralized and comprehensive planning and funding authority, which appears to facilitate the process of planning and financing regional flood control. Large scale projects in the Boston region, such as the Harbor cleanup and the Central Artery Project, involved substantial state and federal resources, which helped to overcome the challenges of collective action. The prospects for substantial resilience funding from federal or state sources are dim, at least in the short-term.

CAPITAL BUDGET CONSTRAINTS

Even when projects show net positive benefits, public agencies and property owners may still lack access to sufficient financing. One reason is that financial markets and investors generally want to see a secure stream of future cash flows, but have little institutional experience with resilience investments and their associated risks and returns. Also challenging is the fact that resilience investments do not necessarily generate revenues; they might make economic sense and be essential to reduce future losses, but may not provide the incremental and predictable revenues investors seek in order to offer affordable bond financing. Municipalities in Massachusetts are constrained in raising taxes by Prop. 2 ½, and the City of Boston caps debt service at 7.5% of the budget in order to preserve its bond rating and access to low-cost financing. At the same time, many municipalities face increasing stress on their capital budgets due to aging infrastructure and deferred maintenance.

MISALIGNED INCENTIVES

Entities with the ability and responsibility to invest in climate resilience are not always the same as those reaping the benefits. There are many sources of these misaligned incentives, which contribute to the challenge of taking collective action. For example, homeowners with access to flood insurance have an incentive to stay in risky areas, and repair and rebuild in the same place after a flood. Developers who build and immediately sell new buildings do not bear the future risk of damage the same way that developers who build and hold for many years do. Similarly, building owners do not bear the full risks of damage to the property of renters or commercial lessees. Federal agencies such as FEMA face political pressures to keep insurance affordable. Municipalities have a strong incentive to increase their tax base through development, even if that might exacerbate longer-term risks from climate change. And municipalities that invest in large-scale flood protection do not directly recoup their costs from the value of the privately-owned buildings they protect.

Flood Barrier along the Thames River in London, England.

4 MECHANISMS FOR *Financing and Incentivizing Resilience Investments*

Many different mechanisms and instruments have been proposed to provide more adequate funding for resilience investments and better aligned incentives.[15] These mechanisms address some of the challenges and market failures that are described above, by helping to overcome collective action problems, providing funding for projects with long-term benefits, and giving incentives and price signals to mobilize private capital. Some of these mechanisms were developed to assist with investments to reduce greenhouse gas emissions (climate mitigation), some are financial tools available for urban development, and some have been piloted for resilience. However, it is important to note that even with innovative and sophisticated financial mechanisms, resilience investments still entail real resource costs and are likely to require new revenue sources.

Different mechanisms are appropriate for different types of projects, scales of funding needed, and type of entity, public or private. This section of the report categorizes and describes mechanisms at three levels:

a. Major region- or city-wide projects, such as a harbor barrier
b. District-level funding, such as projects proposed for East Boston and South Boston
c. Building- or parcel-level projects

Various types of financing mechanisms exist, which we describe in more detail below. Major examples include:

a. Financing instruments, including bonds, loans and forms of collateral
b. Resilience fees, for example, based on property taxes, or water and sewer usage
c. Pricing risk, for example, risk-based insurance and interest rates

These mechanisms are related. For example, revenues from taxes and fees can be used to support bonds. Hybrid mechanisms, such as catastrophe bonds, can combine financing and risk pricing/risk transfer.

These financial mechanisms have various functions, which can be related to the various mechanisms as represented in Table 4.

This is a highly complex field with many options, and in the spirit of the five broad principles laid out in Climate Ready Boston (2016) for climate resilience policy, the various funding mechanisms can be evaluated using some guiding principles.[16] The San Francisco Seawall Finance Workgroup used a similar set of criteria to evaluate, using quantitative scores, a range of funding options to raise $500 million to fortify the downtown waterfront against climate and earthquake risks.

TABLE 4

Functions of Various Types of Financial Mechanisms

	Type of Financial Mechanism					
Functions of Financial Mechanisms	**Bonds**	**Property Taxes**	**Resilience Fees**	**Risk-based Insurance**	**DIF/BID**	**PACE/ PAR**
Transfer financial risks	X			X		
Align incentives			X	X	X	
Stimulate private investment			X	X	X	X
Spread payments over time and many parties	X	X	X		X	
Capture value from parties who benefit		X	X		X	X
Capitalize future benefits	X					X
Provide loan collateral						X

DIF = District Improvement Financing. **BID** = Business Improvement District. **PACE** = Property Accessed Clean Energy. **PAR** = Property Assessed Resilience

Key Principles for Climate Resilience Finance

Revenue generation potential: Ability of financing mechanism to generate sufficient incremental revenues that are predictable and sustainable to match the scale, timing and purpose of the specified project (or a share of it).

Economic effectiveness: The mechanism should have a low cost of capital, including associated transaction costs.

Public-private partnerships: Leverage public funding to mobilize private capital and to overcome collective action challenges to spur action at multiple scales.

Administrative effectiveness: The mechanism should be effective considering the capacity of a city or agency, the time and difficulty in securing any required changes to regulatory frameworks and institutions, and its political acceptability to a broad set of stakeholders. Prior experience with similar models or ability to imitate a program elsewhere with a successful track-record will increase administrative effectiveness.

Fairness and equity: Fairness means that the cost burden broadly reflects benefits provided, by geography, risk reduction, etc. Equity means that the cost burden reflects ability to pay, and the resilience projects do not exacerbate inequalities, for example, by accelerating gentrification. Projects can potentially address equity concerns by providing opportunities for local economic development and workforce training.

Appropriate alignment of incentives: The mechanism should align incentives to help overcome market failures and facilitate flow of capital to projects where the overall benefits exceed the costs, including non-financial aspects, using relevant discount rates. In turn this requires:

- **Leveraging the price of risk,** so that insurance costs, property prices, and interest rates reflect future climate risks, and incentivize appropriate action.
- Using accurate **information and awareness** regarding climate risks and impacts, and the degree of resilience of buildings, infrastructure, and neighborhoods.
- Seeking opportunities to identify, quantify, and monetize **co-benefits**, such as greenhouse gas reductions, public amenities, and reduced risk of business disruption.

Major Region-Wide and City-Level Projects

Even without a harbor-wide barrier, to become climate resilient, some preparedness strategies must extend beyond municipal boundaries.

A region-wide approach to resilience would be costly and require multiple funding sources. That said, it will be essential to coordinate beyond city limits given how interconnected the region is. Many people who work in Boston live outside the City limits and vice versa. Infrastructure investments benefit not just Boston residents and businesses but the regional economy.

One obvious example of this is the idea of a harbor-wide barrier to protect the cities and towns along the Boston Harbor from storm surge. Initial estimates of the cost of a harbor-wide barrier combined with related projects to protect metropolitan Boston are between $7–$15 billion. Federal funds are generally required to cover a substantial portion of major infrastructure projects such as this. For example, post-Katrina investments in flood defenses around New Orleans have cost $14.5 billion, mostly paid by the federal government through the Army Corps of Engineers. The Central Artery Tunnel, or "Big Dig," project in Boston also cost about $15 billion, with federal grants of $7 billion and the Commonwealth of Massachusetts funding the balance through bonds.[19] The project has substantial debt service and operating costs, which are covered, in part, through road tolls and gasoline taxes. The MBTA also issued debt to fund transport improvement commitments that were tied to the project.

For a harbor barrier, the cities and towns that most directly benefit from flood protection might be expected to contribute toward financing the project, in addition to federal and state funding. The extent to which benefits are perceived to be shared across the wider region would likely influence negotiations regarding the allocation of costs. A regional body would need to be established for this purpose. Cities and towns, in turn, would need to recapture value from property owners through various taxes and fees in order to service debt.

Even without a harbor-wide barrier, to become climate resilient, some preparedness strategies must extend beyond municipal boundaries.

Bond Funding for Major Projects

Climate Resilience requires substantial upfront investment and generates benefits over decades, so financing with long-term bonds is an attractive option. These bonds need to be secured against a revenue stream, which would vary according to the type of bond:

- general obligation bonds issued by the state (secured by income taxes or potentially a future carbon tax), municipalities (secured by property taxes), or particular agencies such as the MBTA (secured by revenues)

Community Preservation Act (CPA)

In November 2016, Boston voters overwhelmingly passed a 1% property tax surcharge[17] to generate approximately $17 million per year for affordable housing, historic preservation, recreation and open space.[18] The CPA allows communities to vote to increase this surcharge up to 3%. The CPA therefore provides a legal mechanism to raise additional tax revenues for designated purposes. Using funds for adaptation might require an amendment to the CPA to expand its definition of "community preservation." An additional 1% CPA surcharge would increase funding by about $20 million per year by 2020, close to the amount needed to fund much of the district level investment needed until 2030. The CPA mechanism addresses equity concerns by exempting the first $100,000 of assessed value and has other provisions for low-income and senior residents.

- bonds secured by dedicated funding streams, such as future tax increments, special property tax assessments or fees

The total cost of district-level investments in Boston needed up until 2030 is estimated (very coarsely) to be $1–$2.4 billion. Some of the costs would be covered by federal and state sources. A portion of the costs will be borne by the City of Boston, and potentially other municipalities in the metro region that benefit from a resilient and thriving metropolis. Private property owners would also contribute toward the costs, partly through taxes, assessments and fees, and more directly for properties that are encompassed in a district resilience plan.

Municipalities can finance resilience investments by issuing bonds. Municipal general obligation bonds could be combined with district-level solutions, as discussed further below.

Scale and Purpose: Bonds can range in scale, depending on the issuing agency and project, from tens to hundreds of millions of dollars for municipalities, and up to several billion dollars for states. In March 2018, Governor Baker of Massachusetts filed legislation to authorize over $1.4 billion of capital allocations for climate resilience, environmental protection, and community investments.[20] Bonds can be used to finance major infrastructure and other resilience investments that provide broad public benefits over the long term.

Process: The process for issuing bonds is well understood, has low transaction costs, and does not require new regulations. General obligation bonds are sold to investors by states, municipalities or agencies, and the debt is secured by the ability of the issuing authority to generate revenues, primarily via income taxes for states and property taxes for municipalities. Other bonds are secured by specific revenue streams, for example, The Commonwealth Transportation Bond program, which is rated "AAA" by Standard & Poor's, is secured by revenues from the state's gasoline tax on gasoline and driving-related fees. Bonds to fund resilience projects could either be general obligation, or secured through specific resilience fees.

Strengths: General obligation bonds are backed by the taxation and revenue raising

Green Bonds

Green bonds, which have been growing rapidly, are municipal or corporate bonds intended to fund projects that are broadly considered "green." Various certifications are emerging for green bonds, and they can be attractive for both issuers and investors.[21] Currently, most green bonds are self-designated, and issuers choose to conform to standards set by groups such as ICMA (International Capital Markets Association) or the Climate Bonds Standard.[22] Massachusetts is considered a leader in state and municipal green bonds. In 2013, the state issued a $100 million general obligation green bond.

Green bonds are attractive because they enhance the reputation of the issuer. They can carry lower interest rates, because some investors designate pools of capital for green bonds, increasing the supply of funds for a niche market.[23] Some investors might also accept lower returns because of the broader social and environmental benefits of green bonds. The "green" designation might be of little value for municipalities that already enjoy very low interest rates for tax exempt bonds.

There are not yet broadly recognized accreditation agencies, standardized criteria, or auditing processes for certifying bonds as green.[24] As a result, issuers have considerable discretion, and the label is sometimes viewed cautiously as simply a marketing device. Green bonds do not always attract lower interest rates, and can involve extra costs for certification.

In September 2017, the Massachusetts Bay Transportation Authority (MBTA) issued the first tax-exempt sustainability bond in the nation, valued at $370 million, certified to the ICMA (International Capital Markets Association) standard, and was able to secure lower interest rates.[25] In the last few years the New York Metropolitan Transportation Authority issued several green bonds totaling over $300 million, certified to the Climate Bonds Initiative standard.[26]

capacity of a state, municipality, or agency, and generally have high credit ratings and low interest rates. They can be scaled to meet the expected cost and duration of a project. The cost of servicing debt is relatively low in the current low-interest environment, though rates are likely to rise in the future. Most state and municipal bonds are tax-exempt, keeping interest rates below those for other bonds.

Challenges: Financing through general obligation bonds relies on income and property tax revenues, and is constrained by debt ceiling policies that limit total debt service to preserve credit ratings. For Boston, this limit is 7.5% of revenues or about $220 million a year. Tax revenues, in turn, are restricted by Prop. 2½ and political constraints. Raising taxes or creating new sources of revenues through fees is politically difficult and can require new regulatory authority. It is possible that cities will face credit downgrades due to climate risks, which could make it worthwhile to raise the debt ceiling to finance resilience investments.[27] As interest rates rise, the cost of servicing debt will become more expensive.

Track Record: The market for municipal bonds to finance resilience has been growing rapidly. In 2014, the DC Water Authority issued a $350 million 100-year "green century" bond to improve water quality, climate resilience, and stormwater management.[28] Miami successfully issued a $400 million general obligation bond in November 2017, with about half of the funding targeted for resilience projects, and the balance for affordable housing, road improvements, parks, and economic development.[29] San Francisco is planning a $350 million general obligation bond to fortify the sea wall that protects the downtown waterfront area, though it is not yet clear if the city will seek a "green" designation.[30]

Green infrastructure can reduce stormwater runoff and decrease heat island effect.

Climate Resilience Fees and Carbon Taxes for Major Projects

Given that the scale of investment needed over coming decades is likely to be at least several billion dollars in Massachusetts, even without a harbor barrier, new revenue streams will be needed to support bond financing and operations and maintenance costs. The revenue streams could fund a city, regional or state-level authority or financing agency (or cluster of existing agencies with expanded mandates) that would engage in planning, design, and implementation of climate resilience strategies. Water and sewer fees are advantageous in that they are paid by all facilities—unlike property taxes, from which more than one-third of Boston's properties are exempt. If the fees were raised at the state level, some funding could flow back to cities to support city and district-level projects. A new financing mechanism and authority structure, however, would raise considerable administrative, political, and regulatory issues.

Some authorities, particularly in Europe, are experimenting with a more integrated approach to addressing threats from coastal storm surge and extreme precipitation by establishing flood utilities, funded through a fee based on water and sewer usage, that have the authority to impose fees and use the funds (or bonds secured against them) to pay for resilience measures as well as other services, potentially including fresh water supplies and insurance (see Stormwater Fees sidebar, p. 23). One form of these in the UK are Water Service Companies (WASCOs) that aggregate fees, grants from governmental agencies, and private financing to provide fresh water and flood control infrastructure.[31]

There is little precedent in the US for a large-scale resilience initiative with new funding sources. Northampton, Mass. established a Stormwater and Flood Control Utility in 2014,[32] supported by a controversial new fee,[33] which provides a rare example of a new funding stream to support integrated stormwater and resilience efforts, albeit at a smaller municipal scale. A 2018 California resilience finance report notes that "a combination of factors makes water, sewer, and storm water utilities one of the most readily available sources of funding for resilience infrastructure."[34]

A state-wide carbon tax could generate substantial incremental revenue to support bond financing. This would spread the burden broadly, while also tying the costs to carbon emissions, the ultimate cause of rising climate risks. The tax could be designed to address fairness and equity concerns, depending on how the tax is collected and how the funds would be used or recycled through lower income taxes. A tax would be economically and administratively efficient, but as the experience in Washington State demonstrates, carbon taxes face significant political hurdles, not just because of opposition from carbon-intense business sectors, but also due to conflicts over how funds should be distributed.

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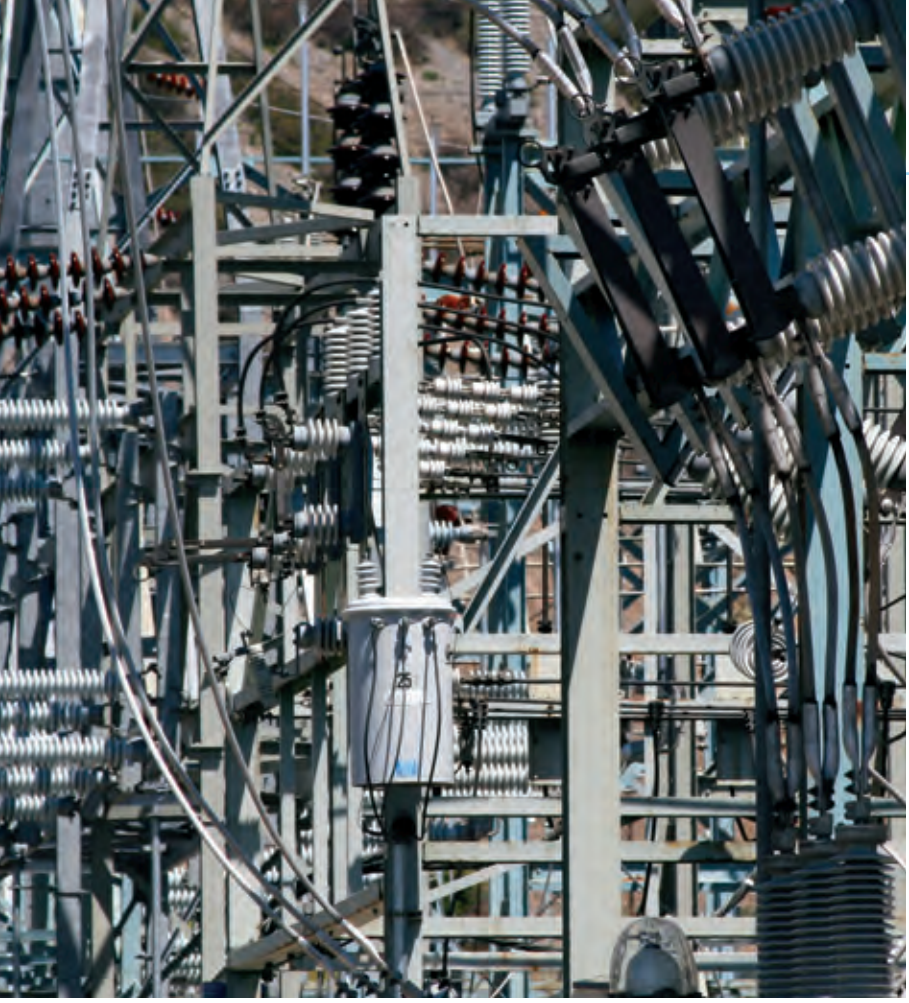
Insurance Surcharge

A state mandated surcharge on all property and casualty insurance policies has been proposed to generate funding for an Adaptation Trust Fund for the New York metropolitan region.[35] A surcharge of 0.5–1.5% would generate $900 million to $2.7 billion in proceeds over 10 years. An insurance-based fee would align costs with the risks to which property is actually exposed (as long as insurance rates themselves are risk-based). Municipal-level resilience investments would lower insurance rates and the surcharge for those protected, but this would mean that properties that do not benefit from these investments effectively subsidize those that do. Property owners who take building-level measures would also enjoy a lower surcharge.



Without investing in resilience, the power grid is vulnerable to climate change impacts.

Enhancing Resilient Infrastructure for Private Utilities

Private utilities that provide power, gas, and telecommunication services play a critical role in disaster recovery and restoration of normal life and business activity. Regulatory authorities therefore have an interest in ensuring that utilities invest in resilience measures to minimize disruptions to service. In 2014, New York mandated ConEdison to invest in hardening infrastructure, and approved a rate increase to fund $1 billion for this.[36] Similarly, in December 2017 the Massachusetts Department of Public Utilities (DPU) required Eversource to assess its climate vulnerability and develop a climate adaptation plan, including proposed metrics and benchmarks. The DPU stated that the planning process would guide future energy infrastructure investments by Eversource, which would be factored into the rate-setting process.[37]

Utilities also benefit from larger region- or district-level resilience investments, and mechanisms need to be instituted for them to pay a fair share of this cost. Utility infrastructure, such as transmission networks and cellphone towers, are not subject to property taxes or water/sewer fees, and therefore fall outside other mechanisms for value capture.

recent attempt to pass a carbon tax in Washington State demonstrates, carbon taxes face significant political hurdles, not just because of opposition from carbon-intense business sectors, but also due to conflicts over how funds should be distributed.[38]

Massachusetts could become the first state in the US to create a state-wide carbon tax, and there are currently two legislative initiatives to do so. Both of them would recycle most of the money to taxpayers, but one of them (H1726) would dedicate 20% to a Green Infrastructure Fund, generating between $200–$300 million a year to finance transportation, climate resilience, and clean energy projects.[39]

Instead of a carbon tax, the state could tap revenues from the Regional Greenhouse Gas Initiative (RGGI). From its 2008 inception through 2017, the RGGI carbon cap-and-trade market has generated $2.8 billion for the nine participating Northeast and Mid-Atlantic states, including $470 million for Massachusetts, to use on energy efficiency, renewable energy, and greenhouse gas mitigation programs. California uses some of the revenues from its cap-and-trade program for climate adaptation, but among the RGGI states, only Delaware does so. These funds are already allocated, but if the cap is tightened and allowance prices rise, incremental revenues will be generated.

Another potential revenue source is the state gasoline tax. Massachusetts' current gas tax is 26.54 cents per gallon, which generated approximately $830 million for the state in FY2017.[40] This rate is among the lowest in the Northeast and Mid-Atlantic, and ranked 30th among all US states.[41] If Massachusetts increased its tax by five cents to pay for climate resilience, it would generate over $156 million per year (though gasoline consumption is gradually declining). This could be allocated to major projects and to various resilience programs for municipalities and property owners. It would also accelerate the move toward fuel efficiency.

District-level Financing

District-level financing relies on a variety of mechanisms to capture value from a targeted district that benefits from publicly financed infrastructure. The funding could be generated by a special assessment on property taxes or a resilience fee based on a surcharge on water and sewer bills. A particularly attractive approach is to use Tax Increment Financing (TIF), termed District Improvement Financing (DIF) in Massachusetts, because instead of levying new fees or taxes, it relies on incremental revenues from private economic development and property value appreciation. As discussed below, however, DIF financing might prove inappropriate for district-level resilience financing.

District Improvement Financing

Tax Increment Financing has traditionally been used to pay for infrastructure to stimulate economic development in designated neighborhoods. Municipalities can designate and create TIF districts (DIF in Massachusetts), and a portion of future incremental local tax revenues are dedicated to pay for the public infrastructure, either to support bond financing or on a pay-as-you-go basis.

Scale and Purpose: DIF bonds are often in the $5–$80 million range depending on the size of the district and scope of the projects. Resilience investments could be the focus of a DIF or integrated into a district's DIF

Business Improvement Districts (BIDs)

BIDs enable property owners in a particular district to raise funds for investments that provide a collective benefit. In Massachusetts the BID mechanism is flexible in terms of what the funds are used for, though there are currently only five BIDs in the state. A proposal is developed that specifies the district, which then needs the support of 60% of property owners representing at least half the assessed value of the property in the district. The city council then needs to approve the proposal, leading to the establishment of a BID as a non-profit organization.

A proposal for a BID to support the maintenance of the downtown Boston Rose Kennedy Greenway has secured the necessary support of property owners and is awaiting approval by the City Council. All the properties in the district directly abut the Greenway, and will pay a levy based on a formula linked to assessed value. The total revenue generated will be around $1.5 million a year from 45 properties. The premise is that maintenance and improvement of the Greenway will enhance property values. Various exemptions exist, for example, for residential condos and for buildings of less than $10 million assessed value.

District Resilience Improvement (DRI) entities could be structured as BIDs in order to levy an assessment on the properties that benefit most directly from the proposed investments. Modifications to the BID mechanism will likely be needed so that they can be tailored for this purpose. The charge should be levied in relation to risk exposure and benefit afforded by the investment. It is likely to prove too complex and expensive to conduct detailed resilience audits for all the properties in a district and develop an agreed algorithm for allocating costs. A simpler approach might be to map properties with, for example, a 10%, 1%, and 0.1% chance of annual flooding by 2030, and designate these as high, moderate, and low risk. These risk designations would determine the resilience tax surcharge in relation to assessed value. To help address equity concerns, various exemptions and discounts for residential property, low-income housing and small businesses could apply. The DRI could also be empowered to negotiate payments from infrastructure owners who benefit from the resilience investments but who would not usually pay property tax, for example, power, gas, and telecommunications utilities, MBTA, and Massport. A formula could be developed to impute a value to the benefits afforded to them.

development program. DIF resilience infrastructure, based on existing state regulations, can include permeable pavement, rain gardens, transportation, seawalls, parks, trees, clean energy, and soft costs related to these improvements.

Process: Creating a DIF district requires defining geographical boundaries, the percentage of tax revenues, and program length (typically up to 30 years).[42] Establishing DIF districts involves standard public approval processes but does not require explicit consent from property owners. Tax-exempt DIF bonds can be issued if the infrastructure is publicly owned and has a public purpose.

Strengths: DIFs are suitable for neighbohood scale investments and capture value from a broad group of property owners who benefit from the projects. Using public funds to stimulate private investment represents a form of public-private partnership. If the DIF stimulates economic development, increases market values of properties, and therefore raises tax revenues sufficiently, the projects will be self-financed. In Massachusetts, DIF borrowing is not included in a municipality's debt limits. The businesses and residents of the district who most directly benefit from the investments also bear the costs, satisfying the fairness criterion.

Challenges: DIFs do not necessarily generate new public revenues, or perhaps not for a number of years, depending on how effectively the public investment stimulates development and raises assessed values. A prolonged period of stagnant property values, due to rising interest rates or a recession, would suppress incremental revenues. The uncertainties attached to the funding stream make it difficult to raise bonds secured against them. New private investment in vulnerable low-income areas can be difficult to attract or can drive gentrification and displacement, raising equity concerns. Municipalities count on rising property prices and tax revenues anyway, and are wary of losing budgetary flexibility by designating revenue streams for particular purposes. DIFs for resilience investments are a particular challenge, because they protect against future damage but might not increase property values and tax revenues, unless carefully bundled with broader value-enhancing development strategies.

Track Record: DIFs have been used sparingly in Massachusetts, but are currently being considered for more projects. One successful example of a DIF was the development of a 40-acre abandoned industrial site in Concord, New Hampshire. Public investment funded by DIF-backed bonds contributed to a redevelopment project comprising a hotel/conference center and low-income housing.[43] San Francisco is planning to finance about $100 million of its $500 million waterfront resilience investment with a targeted Community Facilities District that will impose a special tax on waterfront property owners and businesses.

DIF resiliency infrastructure, such as rain gardens, can reduce stormwater runoff and decrease heat island effect.

Special Tax Assessments and Resilience Fees for District-Level Financing

District-level funding could be generated by a special assessment on property taxes or

Stormwater Fees

Stormwater fees and governance structures potentially provide a model for integrated regional planning and investment in infrastructure to address flooding from extreme precipitation, and could be expanded to cover coastal storm surge and fresh water supplies.

Stormwater management can generate significant co-benefits, such as heat island mitigation, ecological benefits of green infrastructure, and avoided damage and downtime. There are significant positive spill-over effects when one property improves its stormwater management systems, so regulatory codes and incentives are needed. For example, the Ford Rouge Center in Dearborn, Mich. includes a 600-acre green stormwater treatment system with a 10-acre green roof, bioretention swales, porous pavement, and sustainable landscaping. The $15 million project replaced a $50 million water treatment facility and decreased HVAC costs by 5%.

Approximately 1,800 local stormwater utilities currently exist in the United States. They collect fees from residential, commercial and industrial property owners, usually as a surcharge on monthly water and/or sewer billing based on usage/runoff. The fees are used to fund infrastructure investments. Of the 500 New England communities subject to Clean Water Act (NPDES Phase II) stormwater control requirements, only 16 have adopted such a fee system. Annual fees vary from $1 to more than $250 per household.

Stormwater management at the watershed level crosses municipal boundaries, raising problematic governance and finance issues. Financial and governance mechanisms don't yet exist for transfers across municipalities, for example, to enable fees from Boston buildings to pay for upstream investments, or for developers to offset stormwater impacts in Boston with mitigation measures in other communities. Expanding the scope of the MWRA, possibly supervising new watershed agencies, could serve this purpose.

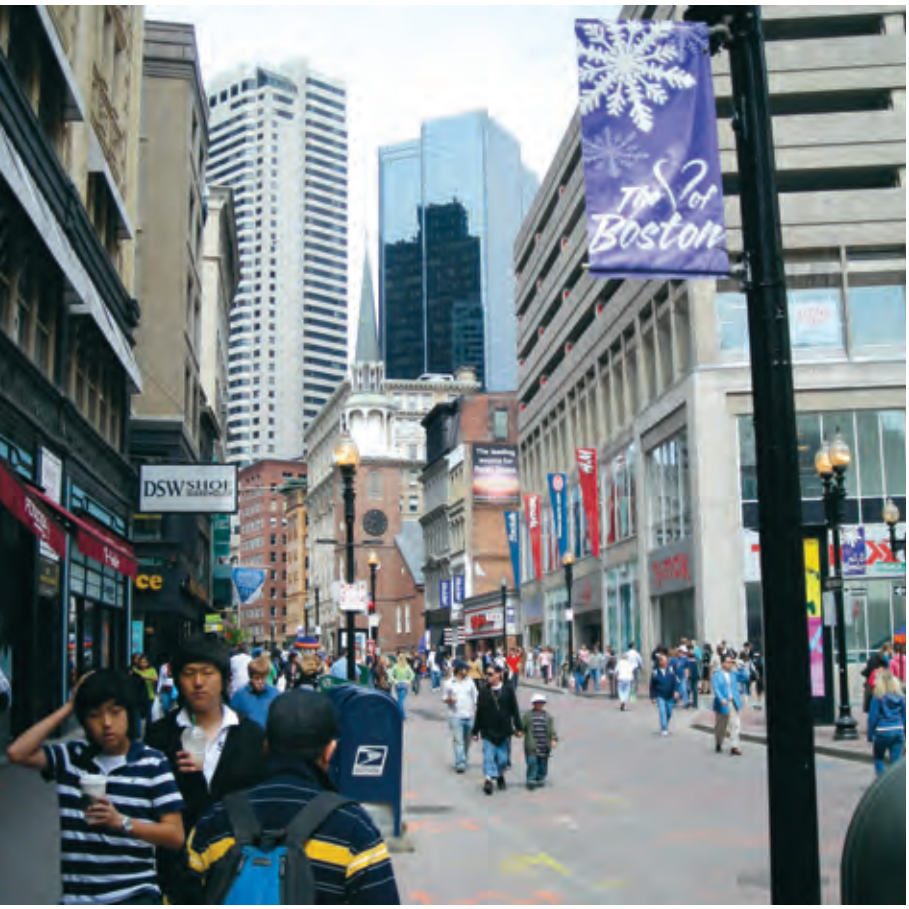
Unlike property taxes, stormwater fees are tied to usage/runoff and apply to all properties, regardless of ownership (Approximately 40% of all buildings in Boston are exempt from property taxes). Property owners may reduce their fees by adopting approved private stormwater management practices and investments to reduce runoff. This strategy is most effective at small to moderate scales (houses to small commercial sites). Stormwater credits may also be used to encourage the purchase and transfer of development rights from rural watersheds to urban neighborhoods.

Stormwater management can generate significant co-benefits, such as heat island mitigation, ecological benefits of green infrastructure, and avoided damage and downtime.

Every New England state except Connecticut has passed legislation establishing a legal basis for collecting stormwater fees. The Boston Water and Sewer Commission in 2015 proposed a stormwater utility fee, but dropped the effort after opponents branded it a "rain tax." Successful adoption of such fees requires focused ratepayer engagement and education.

Milton's stormwater bylaw, which required passage of both Select Board and town meeting votes, established a stormwater utility and collection of "reasonable" stormwater fees.[44] The Select Board sets initial and subsequent rates based on recommendations from Milton's DPW. All properties are evaluated using GIS, assessor and Mass DOR data for land use, property type and amount of impervious surface area. Every property containing impervious surfaces is charged a tiered annual stormwater fee. The Select Board can waive fees for properties that demonstrably meet performance standards established by the DPW. Unpaid fees become a lien on the assessed property.

Milton's stormwater ordinance charges $1.56 per 100SF for larger properties. Assuming one third of Boston's 48 square miles are covered by public roads and rails, the other two thirds of its land base would generate approximately $14 million per year using this fee structure.



Downtown Crossing, Boston. The downtown Boston Business Improvement District (BID) is the first improvement district in Boston.

resilience fees based on surcharges on water and sewer bills, and possibly other utilities and infrastructure, such as tolls. Fees based on water and sewer usage are attractive relative to property taxes because many properties are exempt from property taxes, and there are more legal hurdles and political sensitivities to raising property taxes.[45] Various forms of district-level special tax assessments exist, such as Business Improvement Districts in Massachusetts and Community Facilities Districts (CFDs) in California, which levy a tax surcharge on local property owners, using various formulas, to make investments with common benefits.

Scale and Purpose: Incremental fees or taxes generate new revenues and reflect the price of risk, to the extent that they can be tied to site-specific risk exposure and the protection afforded by the new investment. Fees or taxes will incentivize building owners and developers to avoid high-risk areas or to invest in resilience measures that reduce risks. The formula for calculating the fee or tax could provide for discounts following resilience investments or once specified resilience metrics are met. The principal should be maintained that everyone contributes, however, so that building-level resilience investments do not unduly erode the financial position of the resilience district.

Process: A resilience district would be designated by the city, and property owners (and potentially residents and businesses on leases for resilience fees) would pay a charge to support district-level investments. The process would depend on the type of charge (see "Business Improvement Districts" box, p. 21).

Strengths: A key advantage of fees and property taxes is that they raise new revenues, and they can be targeted to building owners and users who will derive the benefits of resilience projects, and have the capacity to pay. In this way, resilience fees can be used to "recapture" the private benefits of reduced risk and lower insurance costs that flow from public investment in resilience. Fees and taxes are generally simple and low-cost to administer. They can be structured to send a valuable price signal analogous to carbon pricing, incentivizing investments and behaviors that increase resilience. They can be framed as fee-for-service contributions that highlight the benefits within particular districts, with potential discounts for meeting resilience targets, making them more politically acceptable.

Challenges: Resilience fees and taxes directly increase bills, and their visibility can generate political opposition, as in the case of Northampton described above. These charges can also increase inequities for low-income neighborhoods or small businesses, either as owners or if the costs are passed on to renters.

Building- or Parcel-level Financing

Investments to improve resilience at the individual building or parcel level help to ensure that homes and businesses remain in service or recover quickly after a flood. Property owners might benefit directly from lowering their insurance costs, preventing uninsured damage, and reducing business disruptions. Facilities providing important services, including healthcare and food distribution, also provide a public benefit. Some parcels might require investment to form part of wider neighborhood-level protection plans. Property owners are generally not able to capture the full benefits of investments, or might lack the financial resources to make these investments.

Municipalities often leverage major new property development projects by negotiating development linkage payments to provide resources for public purposes. In Boston, developers of residential buildings with 11+ units must make at least 13% of those units affordable or pay Inclusionary Development Funds or "linkage payments." For every square foot above the first 100,000, developers pay $8.34 into the Neighborhood Housing Trust (NHT).[46] Linkage fees for affordable housing currently generate approximately $6.5 million per year.[47]

The linkage payment system could be expanded to require that parcel-level developers align with the district's shoreline protection plan, which will likely incur extra costs. Alternatively, developers could be required to pay resilience linkage fees to support resilience upgrades for affordable housing units. This might entail raising linkage payments overall and/or expansion of the range of developments required to pay the fee.

Building-Level Resilience Loan and Subsidy Programs

Scale and Purpose: Resilience loan programs use dedicated public funding to reduce the cost of financing for homeowners, businesses,

I-Cubed

I-Cubed (Infrastructure Investment Incentive Program) is a Massachusetts program designed to finance significant infrastructure improvements required to support large new private developments.[48] I-Cubed resembles District Improvement Financing but is designed for public infrastructure investments at the parcel-level that offer broader district-level benefits. Investments are financed with bonds backed by future incremental revenues from economic development.

Massachusetts passed legislation in 2008 approving $250 million for this program, with projects ranging from $10 to $50 million, and at least 20% required to be used in economically distressed areas.

Under I-Cubed, public infrastructure improvements for a certified economic development project are financed with bonds issued by Mass Development. During the construction phase of the project, municipalities reimburse the Commonwealth for the debt service cost by levying special assessments on the developer's property.

Once the project is finished and generating new tax revenue for the Commonwealth, the debt service reverts to the Commonwealth. If the new tax revenues differ from the debt service, the municipality either keeps any surplus or covers the shortfall.

$32.4 million of I-Cubed bonds financed infrastructure improvements to support a mixed-use development at Boston Landing in Allston-Brighton. This project includes a commuter rail station, New Balance's worldwide headquarters, parking, retail, restaurant and office space in addition to 1.4 acres of public space.

Boston Landing, Boston. Boston Landing is one of the funded I-Cubed bond improvement sites.

or other entities to invest in increasing the resilience of their properties. The programs generally rely on private capital and banks to issue and underwrite loans, and employ loan guarantees and subsidies to reduce interest rates and closing costs. By leveraging private capital, they are a form of public-private partnership. State-led "green banks" can also be a channel for these loans. The scale is generally up to about $150,000 for residential buildings, and more for commercial buildings.

These programs assist building owners who lack the financial capacity to undertake retrofits, even if they make sense economically. They can also provide incentives for such retrofits. They leverage public funds to stimulate private investments.

Process: The process varies depending on the program. A state "green bank" could issue "green bonds" to fund a program, as in the case of Connecticut's green bank. Another model is the Mass Save program, which relies on a small systems-benefit charge on electricity bills to offer zero-interest loans to finance residential energy efficiency upgrades, as well as free audits and subsidies for retrofits. This could be extended to resilience, potentially funded with a charge on water and sewer bills.

Strengths: These programs assist building owners who lack the financial capacity to undertake retrofits, even if they make sense economically. They can also provide incentives for such retrofits. They leverage public funds to stimulate private investments. Programs such as Mass Save have created a market for retail companies who provide a one-stop shop for property owners to receive free audits, financing, and equipment rebates.

Challenges: These programs often do not provide sufficient funding for low-income retrofits, where property owners lack financial resources and the business case is poor. Many building owners underestimate flood risks and erroneously believe they have adequate insurance coverage. The programs are also generally too small in scale to address neighborhood or regional projects, and funding for them could potentially compete with district-level solutions. Integrated planning is needed to ensure the right balance of parcel and district level resilience solutions. The parcel or building-level business case for resilience is much less clear than for energy efficiency.

Track Record: Connecticut has pioneered the Shore Up program, which provides loans averaging $125,000 to elevate homes in risky locations. The initial funding is expected to be $25 million, which would fund 200 home retrofits, or less than 1% of the 32,000 Connecticut homes in FEMA flood zones.[49] Connecticut's green bank coordinates a range of financing programs for energy efficiency and resilience, acting as a one-stop shop to assist residential and commercial customers in accessing capital. Green banks are usually capitalized with state funds but can also leverage private capital, and provide administrative support and loan guarantees to lower financing costs.

A number of cities and states have existing loan funds for energy efficiency that could be extended to projects that integrate efficiency and resiliency. The New York City Energy Efficiency Corporation has financed over $100 million of projects since it was created and endowed by the mayor's office in 2011. The Mass Save program provides free residential energy audits, zero-interest loans, and rebates on energy efficient equipment. Federal loan agencies also have financing programs that could be used for resilience. For example, Fannie Mae's Homestyle program offers renovation and energy efficiency mortgages.

Property Assessed Clean Energy (PACE)/Property Assessed Resilience (PAR)

PACE financing has been widely used for energy efficiency retrofits in privately owned buildings. PACE loans are secured by a lien on the property and can be transferred to a new owner when a building is sold. This proves attractive to investors and lowers interest rates because it provides more secure collateral than trying to monetize future cost savings. PACE is very similar to a second mortgage, and loan payments are made as an assessment on the owner's property tax bill, collected by the municipality for the banks providing the loans.

PACE/PAR and performance-based financing could work especially well in multi-family residences owned or managed by government agencies, community development corporations, or private entities. Projects undergo pre-investment audits to ensure that energy savings exceed investment and finance costs, creating positive cash flow to support the loan.[50] Interest rates can be quite high on these loans, however, due to the status of the property lien in some states.

PAR can be integrated into PACE-financed projects, allowing resilience retrofits to be bundled with clean energy savings. PAR qualified improvements may include water conservation, flood resistance, hurricane or hail resistant windows and roofing, removal of lead-based paint, asbestos and mold. Massachusetts PACE rules currently exclude resilience measures, however, aside from backup power. PACE programs in San Francisco and Florida do allow for resilience investments.

A quasi-public intermediary agency (e.g. a green bank) is needed to market, administer, and underwrite loan performance criteria and attract private financing for PACE/PAR loans. States and municipalities need to enact a model ordinance developed by the intermediary agency, and administrative fees are involved in underwriting the PACE/PAR loans.

C-PACE (commercial property) programs have been very successful in some states, particularly in Florida.[51] Massachusetts has recently adopted a C-PACE program where individual municipalities can opt-in, with the first financing expected in spring 2018.[51] R-PACE (residential) programs, however, have been hampered by the Federal Housing Finance Agency's (FHFA) need to maintain the first-lien position. Fannie Mae and Freddie Mac are prohibited from purchasing and securitizing primary mortgages with first-lien PACE loans attached. In 2017, legislation was proposed in Connecticut to specify the lien position in a way that addresses FHFA concerns.[53]

PACE financing can be used for energy efficiency retrofits, such as hurricane or hail resistant windows, in privately owned buildings.

5 Risk Pricing and Transfer

The mispricing of risk represents a key market failure that hinders investments in climate resilience. If risk is priced appropriately, it will serve as an important signal to incentivize property owners/managers, developers and investors. This will help mobilize private investment and reduce the need for public financing. The price of risk is analogous to the role of the price of carbon in reducing greenhouse gas emissions—a key tool for policy-makers to leverage.

Various mechanisms have been proposed or are being piloted to align insurance more closely with actual risks and to incentivize resilience investments. These all require improved resilience metrics, standards and disclosures (MSD) to facilitate more accurate risk pricing.

Pricing risk in relation to projections of climate impacts can take several forms:

- Insurance premiums, the most direct measure, and also a risk transfer mechanism
- Current and expected real estate values that reflect risk
- Interest rates for property mortgages and corporate and municipal bonds
- Site-specific resilience fees

Each of these ought to reflect the risks of major climate impacts, but currently markets do not fully incorporate these risks.

Insurance premiums are usually set using historical actuarial data, and the industry is wary of using forward-looking models that might prove inaccurate. Competitive pressures also constrain insurers from raising rates to cover climate risk forecasts. Private insurance companies generally offset longer-term changes in risk by writing policies for only one to two years, but this means that customers do not see a long-term price signal. The National Flood Insurance Program (NFIP) administered by FEMA tends to underprice risk and faces political pressure to maintain affordability.[54] It also relies on historical data, rather than forecasts that incorporate sea level rise. The Biggert-Waters Flood Insurance Reform Act of 2012, which attempted to end subsidies, was stopped by a public outcry, but Congress subsequently did pass legislation to gradually raise NFIP premiums on properties that have flooded repeatedly.[55] Without such risk-based pricing, NFIP's debt has grown to over $20 billion, highlighting the tension between affordability and market pricing.

Various mechanisms have been proposed or are being piloted to align insurance more closely with actual risks and to incentivize resilience investments. These all require improved resilience metrics, standards and disclosures (MSD) to facilitate more accurate risk pricing.

Risk-Based Pricing

FEDERAL DISASTER RELIEF TO STATES

Federal relief from FEMA to states following a disaster declaration has historically not been conditional on any risk mitigation actions, therefore representing "free insurance" that does not incentivize efforts to reduce vulnerabilities. FEMA is considering the implementation of a "disaster deductible" under which states would need to spend a specified amount annually on emergency management and risk reduction in order to earn credits against a deductible in the event of a disaster.[57] The deductible would be determined by a state's fiscal capacity and risk exposure —for Massachusetts, the proposed amount is $9.2 million, and FEMA estimates that it would be $5.1 million net of credit for existing state spending on risk management.

MUNICIPAL AND DISTRICT-LEVEL INCENTIVES

FEMA has instituted a Community Rating System (CRS) to encourage municipalities to reduce flood risks, and allows for discounted NFIP premiums of up to 45%. Municipalities can earn credits for 19 different activities in four categories: public information, mapping and regulations, flood damage reduction, and warning and response. All buildings in a participating community receive the same discount. Boston currently does not participate in CRS.[58] However, only about 5% of the 22,000 NFIP communities participate in CRS. In the Boston metro region, Braintree, Cambridge, Hull and Quincy participate, and building owners enjoy 5–10% discounts on premiums. If district-level resilience investments in Boston lead to NFIP discounts, these would offset, to some degree, incremental fees or taxes needed to pay for the investments.

Participation in CRS can prove politically popular if it saves property owners on insurance. One small city in New Jersey, Avalon, adopted extensive resilience measures that included stricter building codes and investments in drainage systems and floodplain management. As a result, it moved from a

Catastrophe (Cat) Bonds

Catastrophe (Cat) Bonds, developed by reinsurance companies, tap capital markets to provide additional coverage against losses from major natural disasters. They are a form of contingent bond, and represent a hybrid bond/insurance instrument. Investors who buy cat bonds receive interest payments, but risk losing a portion of their principal if a natural disaster exceeds a specified level (e.g., eight-foot storm surge, or losses exceeding $1 billion). Bond sponsors then use these funds to cover losses. Cat bonds are typically short term, with contract terms of 3 to 4 years.

Catastrophe bond interest coupons include two components: a standard interest rate and an interest premium necessary to induce investors to risk disaster-triggered capital losses. Some cat bonds separate these components, so that so that one party just pays the insurance premium component and receives the payouts in the event of a disaster. Essentially, this becomes a form of insurance, where premiums are set by investors' appetite for risk rather than by insurance companies using historical data. Cat bonds are tradeable securities—after the series of severe hurricanes in late summer 2017, Cat bond prices fell sharply, as investors realized that risks might be higher than they had realized.[82]

The New York Metropolitan Transportation Authority (MTA) issued a $200 million parametric cat bond in 2013 to insure against defined storm surge events. This was a rare use of cat bonds by municipal agencies. The insurance was renewed in 2017 at $125 million, but with earthquake coverage added. The cat bond pays out the full $125 million if particular parameters are met, ensuring that the MTA can repair its facilities and remain solvent in the event of a disaster.[84] Parametric insurance that pays a specified amount for defined events are considered to be relatively efficient and low cost.

Investments in resilience would reduce the expected damage from disasters, and should lower the risk premium for cat bonds. A proposal still at the concept stage would capitalize these savings through the creation of resilience bonds, a form of cat bond derivative, to make funds available for cities to invest in resilience.[85] A key challenge here is while individual agencies carry some insurance, many cities do not currently insure against large-scale disasters—so there are no insurance savings to capitalize. Another challenge is the high transactions costs of multiple intermediaries, and the complexity and difficulty in reliably modeling both baseline risk and the reduction from resiliency investments.

Class 6 to a Class 5 rating in 2013, which offers a 25% discount on NFIP rates and translates into over $1 million of savings for property owners.[58] FEMA is considering expanding CRS as well as moving toward a structure-based pricing system in order to price risk more accurately and encourage private building owners to enhance resilience.

In California, where NFIP rates in many areas are considered to be high in relation to actual risks, there is a proposal to establish Community Facilities Districts (CFDs) that would operate Community Choice Flood Risk Financing (CCFRF) to provide residents and businesses an alternative to NFIP flood insurance.[59] The CFDs would levy special taxes on property in the district in order to pay for flood control infrastructure and purchase flood insurance in bulk on the private market. The resilience investments and bulk purchasing would reduce insurance costs.

Developers and building owners will be more likely to invest in resilience if it helps to maintain property prices and reduces costs for insurance and mortgage financing.

BUILDING AND FACILITIES-LEVEL RISK PRICING

Developers and building owners will be more likely to invest in resilience if it helps to maintain property prices and reduce costs for insurance and mortgage financing. One recent study found that homes exposed to sea level rise sell at a 7% discount relative to equivalent unexposed properties, and that the discount has grown over time.[60] Making these market mechanisms work effectively requires a widely accepted set of standards and disclosures for buildings that signals the degree of resilience to the various actors and helps them assess risks more accurately. This would function in a similar way to energy efficiency ratings and disclosures that are mandatory in several cities and states including New York City and California in the US, and in the UK and several other countries.[61]

The voluntary LEED program for certifying green buildings, which focuses on energy efficiency, has been very widely accepted internationally. As of October 2017, Boston requires new buildings subject to Article 80 review to be LEED certifiable and meet targets specified in a Resiliency Checklist for assessing project vulnerabilities and adverse impacts.[62] Green buildings command significant rent and property price premiums (see “Return on Investment,” p. 47).[63]

Several efforts are underway to develop voluntary resilience standards for buildings that could influence property prices and financing costs for mortgages and corporate debt.[64] LEED initiated a pilot credit system for resilient design,[65] which is now being integrated with RELi’s Hazard Mitigation and Adaptation credits.[66] RELi goes beyond LEED in that the certification can be applied to infrastructure, campuses and neighborhoods. The pilot phase includes more than sixty measures that address facility planning, design, operations, maintenance, hazard mitigation, and emergency preparations. The pilot credits are designed to work with other standards such as FORTIFIED and LEED. RELi is designed to serve as an underwriting standard (the Green and Resilient Property Underwriting and Finance Standard), but this stage has yet to be piloted.[67]

The Insurance Institute for Business and Home Safety (IBHS) FORTIFIED program has developed standards for residential and commercial properties that incorporate measures to protect buildings from extreme events as well as accelerate recovery.[68] Alabama currently has the largest number of FORTIFIED certified homes, due to programs that incentivize insurance discounts for homes meeting the standard.[69] The standard also has regulatory incentives in Mississippi, North Carolina, and Georgia. A recent study by the Alabama Center for Insurance Information and Research (ACIIR) found that FORTIFIED-certified homes

The voluntary LEED program for certifying green buildings, which focus on energy efficiency, has been very widely accepted internationally.

commanded a nearly 7% price premium.[70] For the Boston region, A Better City, an organization of business leaders, has assessed and recommended voluntary resilience guidelines for larger commercial buildings, highlighting LEED pilot credits for existing buildings and the RELi checklist for new construction.[71]

Some anecdotal evidence indicates that individual building owners can negotiate lower insurance rates from private insurance companies in return for resilience investments. For example, a ULI report states that a resilient design for a large mixed-use redevelopment at 6 New Street, on East Boston's waterfront, might lead the insurance underwriter Affiliated FM to consider reducing flood insurance premiums substantially.[72] Overall, these standards are still in their infancy, however, and a recent report indicates that awareness and uptake are low among facilities managers, real estate professionals, and the insurance sector.[73]

RISK-BASED INTEREST RATES AND ASSET PRICING

Climate risks affect the ability of property owners, companies and municipalities to repay debt, and therefore ought to affect credit ratings and the interest rates on bonds and mortgages. Mortgage rates, for example, ought to reflect the risk that flooding severely damages a home and the owner is forced to default. Investments in resilience that reduce the risk of default ought to result in lower costs of finance. The RELi, LEED, and FORTIFIED programs, discussed above, are developing metrics that will facilitate market assessment of risk and resilience. Debt markets, however, do not fully incorporate climate risks. In November 2017, Moody's took a first step toward correcting this and informed states and municipalities how it is incorporating climate risks into credit ratings, and warned that high risks could lead to future downgrades.[74]

For corporations, there is increasing pressure to include climate risks in financial reporting and disclosures. These efforts initially focused on carbon emissions and regulatory risk, but more recently are including physical risks and adaptation costs. Several thousand companies globally report information through the London-based Carbon Disclosure Project (CDP) regarding GHG emissions, climate-related risks and opportunities, and management programs and procedures.[75] CDP has recruited around 650 institutional investors with a combined $87 trillion in assets who pressure companies in which they invest for carbon disclosure.[76] The Securities and

Exchange Commission has mandated since 2010 that publicly listed corporations disclose climate risks that might have a material impact on financial results. More recently, the Financial Stability Board's Task Force on Climate-Related Risk Disclosures (TCFD), chaired by Michael Bloomberg and comprising 32 members primarily from the finance and insurance sectors, released a report in June 2017 that recommended publication of climate-related financial information in mainstream annual financial filings.[77] Blackrock and other large investment firms are already encouraging businesses to report using the TCFD guidelines. In December 2017, the UN-affiliated Global Adaptation & Resilience Investment Working Group released *An Investor Guide to Physical Climate Risk & Resilience.*[78]

Integrated Resilience Finance and Disaster Insurance

Coupling disaster insurance and resilience finance is attractive because each component reduces the cost of the other.[86] Currently many municipalities self-insure for minor events and rely on federal disaster aid for assistance after major events. Two relatively simple and low-cost approaches have been discussed by insurance companies and municipalities, but not yet piloted. One approach would be for a municipal agency to issue a longer term cat bond that provides, in one instrument, both finance for resilience investments and insurance against damage.

Another approach is to link bonds for resilience investments with low-cost insurance, but using separate financial instruments. The resilience investments would reduce risks of damage from extreme weather events, therefore leading to lower insurance premiums. The insurance and resilience investments would also protect the credit rating of the municipality and reduce interest rates, because they reduce financial exposure and ensure that the city can respond well to future disasters. There is a role for FEMA or another agency in facilitating a market for cities (or groups of municipalities) to obtain pooled low-cost disaster insurance coverage.

More broadly, many companies now routinely include climate risks in ESG (Environmental, Sustainability, and Governance) data, while other companies use this data to enhance share price valuation models and financial investment strategies. There is clearly growing momentum on the part of regulators, companies, and investors to develop metrics and disclosures that enable financial markets to incorporate risk more accurately into asset values and interest rates. This will encourage private sector investment in resilience.

Contingent Bonds and Insurance-based Financing

Several financial instruments have been proposed that combine resilience financing with risk transfer, in other words, they constitute a hybrid financing-insurance mechanism. There are two key benefits to these integrated mechanisms. First, they transfer some of the risk of project under-performance to investors. Second, they can mutually lower costs—the investment in resilience lowers the risk of damage and therefore the cost of insurance, while insurance coverage reduces credit risk and therefore lowers interest rates for resilience finance.

Contingent, or performance bonds, link repayment to the success of resiliency projects. These can be employed at any level, from companies to municipalities. They transfer some risk from issuing agencies to investors, and can therefore provide a form of insurance against a project not performing well. If project performance generates contractually guaranteed cash flow or cost reductions, this can help to secure finance.

Scale and Purpose: Performance bonds and contracting were developed to facilitate private capital investments in energy efficiency in commercial buildings. The Clinton Climate Initiative launched the *Energy Efficiency Building Retrofit Program* in 2007 to secure unsubsidized commercial lending for efficiency retrofit projects.[79] There is the potential to

apply this mechanism to resilience, or, preferably, to bundle resilience with energy efficiency retrofits in order to reduce costs and use the more predictable cash flow from efficiency. Efficient designs that include high-efficiency windows and tightly sealed building envelopes are likely to enhance resilience to wind and flood damage.

Process: Projected cash flows from energy efficiency projects are used to secure loans. Historic data collected from many similar projects enable savings to be predicted quite accurately, and investors and/or ESCOs (Energy Service Companies) typically guarantee project performance. Larger ESCOs sometimes self-finance and assume the risk of project performance, providing turnkey services that simplify the process and reduce transaction costs.

Strengths: Performance bonds enable commercial building owners to secure private financing against energy future cost reductions. Retrofits can otherwise be difficult to finance. The case studies in The Urban Land Institute's report "Returns on Resilience"[80] highlight the financial value generated by integrating resilience and efficiency upgrades at the time of retrofit and using a single financial instrument.

Challenges: This financing mechanism relies on accurate metrics to predict cost savings, and investors willing to trust these metrics and take on the risk of under-performance. For resilience investments, there is not yet a track record nor standardized metrics for cost savings from lower insurance rates or other sources. Resilience projects are also more idiosyncratic than energy efficiency. This will make investors wary, raising interest rates and increasing administrative challenges.

Track Record: Performance bonds are well established for private sector energy efficiency. The City of Boston, in conjunction with Renew Boston Trust, has been developing a program for municipal buildings, and recently qualified a private ESCO to perform efficiency retrofits on municipal buildings, with a $10 million pilot project. These loans do not affect Boston's debt ceiling because the City is financing the project with loans serviced from earmarked energy savings, and the ESCO assumes the risk of savings falling short. There is also a City plan for a performance bond program for commercial buildings, but this has not yet been implemented.[81]

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A performance bond for resilience was piloted at the municipal level by DC Water, which issued an environmental impact bond in September 2016 to finance green infrastructure to meet EPA consent decree requirements. The bond carries standard interest rates, but links performance payments to the success of the project in managing stormwater.[82] If the project underperforms, investors must reimburse DC Water; if it overperforms, DC Water will make extra payments to investors. The Rockefeller Foundation, in collaboration with Quantified Ventures, is now funding the development of two pilot projects in other cities. The performance metrics for stormwater are based on sewer flows for given rainfall events.

6 Existing Resilience Funding Sources

Many programs and funding sources already exist at federal, state, and municipal levels, which can be utilized to partially fund resilience projects, depending on their purpose, scale, and ownership. Resilience projects often generate multiple benefits, so they are frequently eligible for multiple funding sources, such as transportation, FEMA, and water grants. It would be worthwhile to develop a full exposition of sources.

Resilience projects often generate multiple benefits, so they are frequently eligible for multiple funding sources, such as transportation, FEMA, and water grants.

Funding sources can be classified in three ways:

1. Programs explicitly designed for resilience projects
2. Programs for post-disaster recovery
3. General programs for infrastructure funding

1. Programs Explicitly Designed for Resilience Projects

The Congressional budget deal approved in February 2018 designated $12 billion for hazard mitigation from extreme weather events, the largest single budget allocation for resilience. Communities affected by extreme weather events between 2015 and 2017 are eligible to apply for mitigation grants.

FEMA's Hazard Mitigation Assistance provides funding through three major long-standing programs.[87]

- Hazard Mitigation Grant Program (HMGP) for implementing long-term hazard mitigation measures following a major disaster
- Pre-Disaster Mitigation (PDM) provides funds for hazard mitigation planning and projects on an annual basis
- Flood Mitigation Assistance (FMA) funds projects to reduce risk of flood damage to buildings that are insured under the National Flood Insurance Program (NFIP)

Several programs at the state level are available in Massachusetts, for example:

- The Mass. Office of Coastal Zone Management (CZM) administers the Coastal Resilience Grant Program to provide financial and technical support for efforts to increase understanding of climate impacts, identify and map vulnerabilities, conduct adaptation planning, redesign vulnerable public facilities and infrastructure, and implement non-structural (or green infrastructure) approaches to resilience.[88]
- MassDEP's Water Utility Resilience Program (WURP) is a technical assistance program designed to support Drinking Water (DW) and Wastewater (WW) utilities in enhancing their resilience to hazardous weather events.[89]

A number of international sources of funds are being established to finance climate adaptation efforts at the subnational level. For example, in 2017 the R20 Regions of Climate Action coalition, which includes the Leonardo DiCaprio Foundation and BlueOrchard, an impact investment manager, launched the Subnational Climate Fund (SnCF). The fund has already received commitments for $100 million with a goal of $350 million. It is designed to fill gaps in funding for climate solutions at the subnational level, mostly in Africa and other developing countries. The World Bank's City Creditworthiness Initiative plans to facilitate municipal access to financing for resilient urban infrastructure. The ICLEI Transformative Actions Program similarly is targeting capital flows to cities, towns, and metropolitan regions.[90]

The vast majority of disaster recovery funding becomes available only after the Federal Government declares an area to be a natural disaster under the Stafford Act. Unfortunately, this funding is nearly impossible to use for pre-disaster preparedness improvements without legislative changes.

2. Programs for Post-disaster Recovery

The February 2018 Congressional budget deal allocates nearly $100 billion in supplemental funding for disaster recovery, including $28 billion to the Department of Housing and Urban Development's (HUD) Community Development Block Grant (CDBG) program for repairing homes, rebuilding infrastructure, and supporting disrupted businesses.[91]

New Orleans was a major FEMA site following Hurricane Katrina in 2005.

TABLE 5

Federal Grant and Other Funding Programs

Federal Grant Program	Sponsoring Agency	Requires Declared Disaster	Eligible Projects
Hazard Mitigation Grant Program	FEMA	Yes	Reduction of flood risk
Pre-Disaster Mitigation Program	FEMA	No	Reduction of flood risk
Flood Mitigation Assistance Program	FEMA	No	Reduction of flood risk
National Disaster Resilience Competition	HUD	No	Reduction of disaster risks
Community Development Block Grants	HUD	No	Resilient community improvements
Regional Resiliency Assessment Program	Homeland Security	No	Planning for resilient infrastructure
Coastal Resilience Grants	NOAA	No	Resilient coastal infrastructure
Office of Coastal Management Grants and Cooperative Agreements	NOAA	No	Coastal resilience planning
National Sea Grant College Program	NOAA	No	Coastal resilience planning
Standard Projects; Continuing Authority Program	ACE	No	Reduction of storm & flood risk, beneficial use of sediment, aquatic ecosystem restoration
Planning Studies	ACE	No	Areawide studies not focused on a specific project
San Francisco Bay Water Quality Improvements Fund	EPA	No	Restore wetlands and watershed, and reduce polluted runoff
Water Infrastructure and Resiliency Finance Center	EPA	No	Information center for drinking water, wastewater, and storm water infrastructure finance

Acronym Key: FEMA refers to the Federal Emergency Management Agency; HUD refers to the Department of Housing and Ureban Development; NOAA refers to the National Oceanographic and Atmospheric Agency; ACE refers to the Army Corps of Engineers: and EPA refers to the Environmental Protection Agency.

Source: Finance Guide for Resilient by Design Bay Area Challenge Teams, 2017

By far the largest pool of funds is for general infrastructure funding and deferred maintenance. These funds can be used to address resilience goals by using regulatory tools and incentives to ensure that new infrastructure, upgrades, and maintenance reflect appropriate resilience standards.

The vast majority of disaster recovery funding becomes available only after the Federal Government declares an area to be a natural disaster under the Stafford Act. Unfortunately, this funding is nearly impossible to use for pre-disaster preparedness improvements without legislative changes to Sections 404 and 406 (Hazard Mitigation Grants) of the Stafford Act.

3. General Programs for Infrastructure Funding

By far the largest pool of funds is for general infrastructure funding and deferred maintenance. These funds can be used to address resilience goals by using regulatory tools and incentives to ensure that new infrastructure, upgrades, and maintenance reflect appropriate resilience standards.

Useful summaries of government agency funding sources for resilience can be found in other reports and websites. For example, NOAA maintains a list of funding sources on its Climate Resilience Toolkit website.[92] Table 5 above is from the Finance Guide for Resilient by Design Area Challenge Teams:[93]

7 Key Conclusions and Recommendations

Key Conclusions

1. We Need More Accurate Pricing of Risk

Risk needs to be priced more accurately in order to create appropriate incentives to individuals, businesses and municipalities for investments in resilience. The price of risk is reflected in insurance costs, property prices, resilience fees, and mortgage and bond financing rates. Each of these requires specific policies that help to correct the market failures that currently distort the price of risk. Pricing risk more accurately will mobilize substantial amounts of private capital for resilience and save on insurance costs.

2. Stakeholders Need Standardized Metrics

The development of widely-accepted metrics and standards for resilience at multiple scales, from buildings to businesses to cities, can facilitate more accurate pricing of risk. Disclosing risks and resilience measures could be mandated for buildings meeting particular thresholds, or might be pushed by market forces. For example, insurers and bond rating agencies might require resilience disclosure to enable risk-based pricing of insurance and interest rates. Such metrics and standards will also serve as a governance tool that can be incorporated into regulations, loan underwriting standards, or as a private, normative mode of governance.

3. There Is No Silver Bullet

There is no single simple financial solution for resilience. As with climate mitigation, adaptation will require a range of policies and funding mechanisms from federal, state, municipal, and district levels. These should leverage private capital as well as public sources of revenues, and include a range of funding streams, from carbon or gasoline taxes at the state level, to resilience fees based on water and sewer bills, to mechanisms based on property taxes, such as Business Improvement Districts that rely on special assessments.

Street flooding at Neponset Circle in Dorchester, Boston. March 2018.

Solar panels and other energy efficiency measures provide revenue streams in a way that most resilience investments do not.

4. Spread the Cost Burden

Spreading the burden over multiple levels and a range of funding mechanisms will make resilience investments (a) financially and politically feasible (b) affordable for households and businesses, without raising bills unduly, and (c) ensure that those who benefit more directly (i.e. at the district level) pay more, while those who benefit more indirectly pay less, but still contribute to the resilience of the region. Overall, these provide the mechanisms to pay for specific solutions that are identified through CRB Strategy 5: "create a coastal protection system."

5. More Value Capture Mechanisms for Climate Resilience Are Needed

Major projects to protect neighborhoods and the metro region will largely be designed and financed by public agencies, and the costs will exceed the current financial capacity of these agencies. There is a need for "value capture" mechanisms that generate new funding from those who benefit from the investments, primarily property owners and businesses, including private utilities and public agencies that own infrastructure in areas to be protected.

6. Ensure that New and Upgraded Infrastructure and Buildings are Resilient

Very large amounts of capital will be spent by state and municipal agencies as well as businesses in coming decades on new and upgraded infrastructure and buildings. In Massachusetts, the MBTA and Massport will be spending substantial sums to upgrade their facilities. These sources of capital dwarf dedicated "resilience funds" and should be leveraged, in combination with available federal and state funding sources, to further climate resilience goals by strengthening regulatory tools, voluntary resilience standards, and financial incentives.

7. There Is No Free Lunch

Enhancing resilience will require mechanisms to generate new revenues. Climate resilience investments help avoid future losses but do not easily generate substantial cash flows. There are no free lunches—however creative the financing, investments have a real resource cost, and opportunities for co-benefits are more limited than with, for example, energy efficiency and clean energy. The resource costs have to be borne in the near future, but generate long-term benefits, which can be difficult to monetize and capture. Some co-benefits do exist. For example, resilient properties carry a price premium, and at the neighborhood level, there is the potential for enhanced leisure and aesthetic value, with spill-over effects for property values and local economic development.

8. Refine the Business Case

Making a clear business case is critical to leverage private investment in resilience. Similarly, cost-benefit analysis needs to demonstrate net benefits to justify public investment (see Appendix B for a more detailed discussion of Return on Investment and Cost-Benefit Analysis). The business case for resilience, however, is not as clear as that for energy efficiency and clean energy. Existing studies indicate that incremental investments in resilient and green new buildings have a solid financial return, but that retrofits on existing buildings need to integrate energy efficiency with resilience to justify investment. Cost-benefit analysis of major infrastructure projects generally points to net benefits (benefit-cost ratios greater than 1) for medium to severe climate scenarios, and with low discount rates, but marginal or negative net benefits for nearer term, more modest climate impacts, and/or higher discount rates. More refined, comprehensive, and standardized metrics and estimation protocols would be valuable.

9. Solutions Need to Be Equitable and Fair

Climate resilience financing mechanisms need to take account of fairness and equity concerns. Fairness means that payments need to relate to benefits, primarily in terms of risk exposure, protection afforded by the investment, and also contribe to greenhouse emissions that drive the need for adaptation. Equity means that mechanisms need to account for ability to pay. Equity also entails community participation in decision making, and ensuring that climate resilience investments benefit local communities not just through flood protection, but also through improved housing and infrastructure, access to employment and healthcare, workforce development and the use of local contractors and labor, thereby recycling money into the local economy.

There is scope to encourage markets for low-cost resilience finance in combination with low-cost disaster insurance. The resilience investments would reduce risks, therefore leading to lower interest rates on the bonds as well as lower insurance premiums.

10. Finance and Insurance Can Be Creatively Combined

There is scope to encourage markets for low-cost resilience finance in combination with low-cost disaster insurance. The resilience investments would reduce risks, therefore leading to lower interest rates on the bonds as well as lower insurance premiums. The insurance would also ensure that cities or companies can respond well to future disasters and remain solvent, further reducing the rate on the bonds. An agency at the state or city level could facilitate low-cost parametric insurance that covers multiple agencies and districts on a bundled basis.

Recommendations

We have six specific recommendations for actions to advance resilience financing:[94]

1. Create a Resilience Financing Implementation Working Group for the Boston metro region
2. Use a mix of funding sources to cover the costs of resilience investments
3. Establish a state-level Climate Resilience Fund
4. Issue general obligation bonds with new funding streams
5. Establish District Resilience Improvement (DRI) entities to finance district scale projects
6. Expand Mass Save program to incentivize building resilience improvements

1. Create a Resilience Financing Implementation Working Group for the Boston Metro Area

The creation of a Climate Resilience Finance Implementation Working Group for the Boston metropolitan (or wider) region would be a valuable step toward implementing climate adaptation measures, designing specific financing mechanisms and disclosure protocols, coordinating with municipal and state officials regarding regulatory changes needed, and facilitating communication with a wider group of stakeholders. Coordinating plans and mechanisms among federal, state, city, and district levels would be an important objective. The RFIWG would comprise senior level people with relevant expertise from municipalities, business sectors such as insurance, finance, accounting, property developers, and CDCs. It would be important to include representatives from community groups so that equity concerns are included in the discussion and design of financial and disclosure mechanisms.

2. Use a Mix of Funding Sources to Cover the Full Costs of Resilience Investments

Total Needs in Boston until 2030, exclusive of a harbor barrier, are estimated at $1–$2.4 billion. It is not realistic for the City of Boston to finance 100% of its resilience needs from existing general tax revenues and capital budgets. A mix of funding from different scales of government, as well as private capital, is needed. We recommend considering a four-way split of funding from federal, state, city and district sources. Private capital will be more directly relevant at the parcel level. The table below provides one possible scenario for this layered approach to funding.

FEDERAL FUNDING

The federal government has traditionally funded about 50% or more of major infrastructure projects, but we are assuming this support might only be 25–30% going forward, due to political and macroeconomic factors.

TABLE 6

Layered Funding Sources Scenario

Scenario	Proportion of Total	Total $M for Boston	Annual Revenues to Service $M	Revenue Source
Total	100%	1,000–2,400		
Federal	25–30%	250–720		Various existing programs
State	25–30%	250–720	17.2–49.8	Carbon or gasoline tax; RGGI
City	20–25%	200–600	13.8–41.5	Bond serviced by water/sewer fee
District	15–20%	150–480	10.3–33.2	Property tax-based, e.g. BID
Parcel/Building	Additional to est. total			Extended Mass Save program

STATE-LEVEL FUNDING

As one scenario, Massachusetts could create a new carbon-based revenue source of $150 million/year from 2021 to 2030, which would raise $1.5 billion over that period. This could support a bond of $2.15 billion (20 years, 3.5% interest rate). Municipalities in the Boston region would expect to secure a significant portion of that funding in relation to their assets at risk and climate resilience plans.

CITY-LEVEL FUNDING

As one scenario, a general obligation bond issued by the City of Boston for $260 million would cost approximately $18 million a year to service (20 years, 3.5% interest). This would represent about 5.2% of Boston's total water and sewer bills, or about 0.9% of total property tax revenues for the City.

DISTRICT-LEVEL FUNDING

The districts requiring major investments would create Business Improvement Districts (BID) or similar vehicles. If the total funds needed for all the districts is about $200 million, this would require revenues of about $14 million a year to support a 20-year bond.

3. Establish a State-Level Climate Resilience Fund

We recommend that the Commonwealth of Massachusetts establish a climate resilience fund to assist municipalities, businesses, and homeowners with necessary investments. The funding would be channeled through existing programs, such as Mass Save, and through new ones to be created for the purpose. All communities in Massachusetts, not just those near the coast, will face climate risks due to more severe storms that bring wind and extreme precipitation, as well as extreme heat and potentially drought. Enhancing resilience benefits the state as a whole and improves the security, quality of life, and competitiveness of the region. Projects that enhance the resilience of infrastructure of the wider region, such as the airport and transportation tunnels in East Boston, should receive a larger share of revenues to reflect these benefits.

Massachusetts is considering a state-wide carbon tax, which could be used to finance transportation, climate resiliency, and clean energy products.

> The federal government has traditionally funded about 50% or more of major infrastructure projects, but we are assuming this support might only be 25–30% going forward, due to political and macroeconomic factors such as growing deficits.

Several sources of funding could generate substantial revenues while also reducing carbon emissions, the ultimate driver of climate risks:

- **A state-wide carbon tax:** Massachusetts could become the first state in the US to create a state-wide carbon tax, and there are currently two legislative initiatives to do so. Both of them would recycle most of the money to taxpayers, but one of them (H1726) would dedicate 20% to a Green Infrastructure Fund, generating between $200—$300 million a year to finance transportation, climate resiliency, and clean energy projects.[95] The tax could be

Once the City of Boston completes the neighborhood resilience strategies, funding from municipal bonds would be a good way to fund some elements of these projects. Municipal bonds could also help fund coordinating investments for adapting infrastructure to future climate conditions.

designed to address fairness and equity concerns, depending on how revenues are used or recycled through lower income taxes.

- **The Regional Greenhouse Gas Initiative (RGGI):** The RGGI carbon cap-and-trade market has generated $470 million for Massachusetts from its 2008 inception through 2017. This has promoted energy efficiency, renewable energy, and greenhouse gas mitigation programs. California uses some of the revenues from its cap-and-trade program for climate adaptation, but among the RGGI states, only Delaware does so. These funds are already allocated, but if the cap is tightened and allowance prices rise, incremental revenues will be generated.
- **The state gasoline tax:** Massachusetts' current gas tax is 26.54 cents per gallon, which generated approximately $830 million for the state in FY2017.[96] This rate is among the lowest in the Northeast and Mid-Atlantic, and ranked 30th among all US states.[97] If Massachusetts increased its tax by five cents to pay for climate resiliency, it would generate over $156 million per year (though gasoline consumption is gradually declining).

4. Issue General Obligation Bonds with New Funding Streams for Some Portion of Resilience Investments

The City of Boston could issue general obligation bonds backed by property taxes or a new resilience fee based on water and sewer bills. The cost of servicing debt is very low for Boston due to its excellent credit rating and the current low-interest environment, though rates are likely to rise in the future. Most state and municipal bonds are tax-exempt for projects that serve the public interest, keeping interest rates below those for other bonds. Investing in resilience will help ensure that Boston avoids credit downgrades due to climate risks, which could make it worthwhile to raise the debt ceiling.[98] Boston could consider a "green bond" designation to assist with marketing and maintaining low interest rates.

The market for municipal bonds to finance resilience has been growing rapidly. In 2014, the D.C Water Authority issued a $350 million 100-year bond to improve water quality, climate resilience, and stormwater management.[99] Miami successfully issued a $400 million general obligation bond in November 2017, with about half of the funding targeted for resilience projects.[100] San Francisco is planning a $350 million general obligation bond to fortify the sea wall that protects the downtown waterfront area.[101]

Once the City of Boston completes the neighborhood resilience strategies, funding from municipal bonds would be a good way to fund some elements of these projects (CRB Strategy 4). Municipal bonds could also help fund efforts to coordinate investments for adapting infrastructure to future climate conditions (CRB Strategy 6 and Strategy 7). Funds from a resilience bond, especially if it was serviced through resilience fees based on water and sewer usage, could be used for green infrastructure (CRB Strategy 8).

Extending the Community Preservation Act (CPA) would provide a mechanism to raise additional tax revenues for designated purposes, though using funds for adaptation might require an amendment to the CPA to expand its definition of "community preservation." In November 2016, Boston voters passed a 1% property tax surcharge to generate approximately $17 million per year for affordable housing, historic preservation,

recreation and open space.[102] The CPA allows communities to vote to increase this surcharge up to 3%. An additional 1% CPA surcharge would increase funding by about $18 million per year, rising with assessed property values. The CPA mechanism addresses equity concerns by exempting the first $100,000 of assessed value and other provisions for low-income and senior residents. Given CPA's focus on recreation and open space, additional resilience funds could be used to fund CRB Strategy 8, which focuses on green infrastructure.

We suggest that Boston consider servicing the resilience bond with newly instituted resilience fees based on water and sewer usage, and extent of impervious surfaces. Discounts could be available based on new resilience investments and/or metrics that reflect prior investments as well. This could entail creation of a new municipal water and flood utility, similar to the Northampton, Mass., model. Water and sewer fees are paid by all facilities, unlike property taxes. Water/sewer-based fees are generally perceived to be appropriate for infrastructure to secure fresh water supplies and avoid flooding not just on the coast but inland. Spreading costs between a water/sewer-based fee at the city level, and a risk-adjusted property-tax charge at the district level (where there are generally fewer tax-exempt buildings), should make the resilience financing system more equitable.

5. Establish District Resilience Improvement Entities to Finance District-Scale Projects

The key districts requiring substantial resilience investment will need to create District Resilience Improvement (DRI) entities that levy fees on the properties that benefit most directly from the proposed investments. A separate DRI would be established in each district, i.e. East Boston, South Boston, Downtown, etc. Due to the concerns with District Improvement Financing discussed

Flooding at the MBTA Aquarium Station in downtown Boston. March 2018.

in the report, we suggest that Business Improvement Districts or similar framework be used as a vehicle, perhaps with modifications tailored for this purpose. BIDs use a formula to levy a surcharge on property taxes, but cannot be a fixed percentage of assessed values.

The Mass Save program assists building owners who lack the financial capacity to undertake retrofits, even if they make sense economically. They leverage public funds to stimulate private investments.

We suggest that the charge be levied in relation to risk exposure and benefit afforded by the investment. It is likely to prove too complex and expensive to conduct detailed resilience audits for all the properties in a district and develop an agreed upon algorithm for allocating costs. A simpler approach might be to map properties with a 10%, 1%, and 0.1% chance of annual flooding by 2030, and designate these as high, moderate, and low risk. These risk designations would determine the resilience tax surcharge as a percentage of assessed value and could be used in implementing CRB Strategy 11: insure buildings against flood damage. To help address equity concerns, various exemptions and rate differentials for small businesses and low-income housing could apply. Discounts could be given to property owners who invest in building-level resilience, though an important principle would be that everyone contributes to district level protection, as resilience requires layered measures.

A key function of the DRI would be to coordinate with the City on the master plan for the district and combine funding from multiple sources to finance the plan. The DRI would negotiate with individual parcel owners over the apportioning of costs for redeveloping or retrofitting sites. The plans for individual parcels, especially those near the waterfront perimeter, will need to be aligned with the district-level master plan in order to ensure continuity of protection, stormwater management, egress, and so on. Parcel owners would be expected to contribute a portion of the cost as they redevelop or retrofit a site. This could be equivalent to the cost of an open space protective berm or other kind of "green" buffer, a simple seawall or other building flood protection, and the DRI would fund the balance needed to align with the master plan. The DRI would also negotiate payments from infrastructure owners who benefit from the resilience investments but who would not usually pay property tax, for example, power, gas and telecommunications utilities, MBTA and Massport. A formula could be developed to impute a value to the benefits afforded to them.

6. Expand Mass Save to Incentivize Building-level Resilience

One of the key challenges with climate resilience is addressing the current building stock. CRB Strategy 10 is focused on retrofitting existing buildings. To provide incentives and finance for resilience upgrades for all buildings, we propose an extension of the Mass Save program. It currently relies on a small systems-benefit charge on electricity bills to offer free audits, zero-interest loans, and subsidies for energy efficiency retrofits. This could be extended to resilience and to smaller commercial buildings. (Larger commercial buildings that form part of the shoreline protection perimeter would be administered within the district-level DRI plan—but these buildings could potentially also be eligible for Mass Save incentives). There is a strong business case for integrating energy efficiency and resilience into new building design and retrofits; energy efficiency usually has a clear positive return, and resilience is relatively inexpensive when integrated into the same project.

The Mass Save program assists building owners who lack the financial capacity to undertake retrofits, even if they make sense

The Mass Save program assists building owners who lack the financial capacity to undertake retrofits, even if they make sense economically.

economically. It leverages public funds to stimulate private investments. Programs such as Mass Save have created a market for retail companies who provide a one-stop shop for property owners to receive free audits, financing, and equipment rebates. These programs often do not provide sufficient funding for low-income retrofits, where property owners lack financial resources and the business case is poor, so provisions would need to be made, such as more generous subsidy levels or longer repayment terms.

Mass Save is a state level program that delivers programs to individual property owners using third-party retail-level companies that perform audits and assess potential upgrades, aggregate sources of funding, and perform installations. These companies would need to expand their expertise and capacity to include resilience. As part of their service, they could partner with insurance companies to offer discounts reflecting the reduced risks. As a state-level program, the incremental funding needed to cover resilience in Mass Save could be derived from the suggested carbon taxes, gasoline taxes, or other sources described above. Some funds could be redirected from energy efficiency toward resilience, as efficiency requires less subsidies than in earlier years. The fund could also be supplemented with a small charge on water and sewer bills statewide, or targeted toward areas at risk and eligible for resilience assistance funds.

Looking to the Future

There is a growing realization that the future growth and prosperity of the region demand that sound investments be made to enhance climate resilience and reduce the risk of major disruptions to the economy and dislocation of vulnerable communities. Moving forward will require political will, courageous leadership, and closer collaboration with local communities and businesses. Together we can develop the regulatory and market frameworks needed to address this challenge and ensure the future sustainability and wellbeing of the region.

APPENDIX A

MAPPING CLIMATE RESILIENCE FINANCE ONTO CLIMATE READY BOSTON

Many of the "initiatives" in Climate Ready Boston are focused on planning and assessing the current situation. Much of this work can be done with internal shifts in budgets or grant funding. Potentially, a percentage of the revenues generated from the financing mechanisms outlined above could be used for planning, administration and coordinating purposes. For the most part, this report focuses on identifying funding for physical resilience projects and capital expenditures. Below are the Climate Ready Boston "strategies" which, once the initial initiatives are completed, will require substantial funding with connections to possible funding sources in this report.

TABLE A1

Potential Funding Mechanisms for Climate Ready Boston

CRB Strategy	Potential Funding Mechanism	Pages
5. Create a Coastal Protection System	All funding mechanisms are relevant.	Pages 14–27
6. Coordinate investments to adapt infrastructure to future climate conditions Note: While this strategy is only focused on coordination, eventually we will need to make big investments in infrastructure upgrades.	Resilience Bonds Carbon/Gasoline Tax/Resilence Fees Existing Federal/State Sources	Pages 16–18 Pages 19–20 Page 36 (Table 5)
7. Develop district-scale energy solutions to increase decentralization and redundancy	Carbon Tax/Gasoline Tax/RGGI Public–Private Partnerships	Pages 19–20 Pages 21–24
8. Expand the use of green infrastructure and other natural systems to manage storm water, mitigate heat and provide additional benefits	Resilience Bonds Resilience Districts Stormwater Fee	Pages 16–18 Pages 21–24 Page 23
10. Retrofit existing buildings	Resilience Districts Mass Save Extension PACE/PAR	Pages 21–24 Pages 25–26 Page 27
11. Insure buildings against flood damage	Insurance and Risk management	Pages 28–33

APPENDIX B

EVALUATING RESILIENCE INVESTMENTS: RETURN ON INVESTMENT AND COST-BENEFIT ANALYSIS

The costs of extreme weather events point to the need for investments to increase resilience. Hurricanes Katrina, Sandy, and in the summer of 2017, Harvey, Irma, and Maria, not only led to substantial loss of life, but also created massive damage to property, infrastructure and lost business. There are many potential investments that could reduce these impacts, from large-scale harbor-wide projects to neighborhood schemes, such as berms and raising roadways, to investments in making individual buildings more resilient.

Making decisions regarding which investments to pursue (or when) is complex because future losses are not always easy to forecast and quantify. Potential investments also interact in complex ways—a harbor barrier might take many years to plan and build, and preempt the capital required for local and quicker adaptation investments. It might also have additional and unexpected impacts, for example, on the harbor ecosystem and fishing. Local district-level investments might need to be supplemented over time with measures to protect other flood pathways as sea levels rise. Recognizing the threat of climate change and limited resources, we need mechanisms to evaluate potential investments and guide decision making.

Private versus Public Investments

The sheer magnitude of investment that is needed for cities to become "climate ready" demands the participation of private sector investors. These investors make decisions that are largely driven by return on investment (RoI) calculations. A common measure of RoI is Net Present Value (NPV), which needs to be greater than zero at a given cost of capital or target return (The Internal Rate of Return, IRR, is also used by private investors, which will be greater than the cost of capital when NPV is positive). NPV is calculated simply by listing all the various costs and revenues from a project, applying an appropriate discount rate for future sums, and adding them up. RoI for private investors only takes into account actual or expected cash flows. As a result of many market failures, private investors do not account for some of the benefits (and costs) of resilience investments, creating serious hurdles. Public authorities can overcome these hurdles, to some degree, either by undertaking the investments themselves or by changing the incentives facing private investors.

As a result of many market failures, private investors do not account for some of the benefits (and costs) of resilience investments, creating serious hurdles. Public authorities can overcome these hurdles, to some degree, either by undertaking the investments themselves or by changing the incentives facing private investors.

Seawalls are an example of a shore-based solution that can provide protection against storm surge as well as safe access to the ocean.

Since they are serving the public interest, public entities need to take account of a larger set of factors in considering the value of an investment. They need to consider financial impacts on others; for example, building a sea-wall might reduce insurance costs for building owners, which the city should count as a benefit even if it does not recapture the gains. Similarly, a public entity needs to account for non-financial costs and benefits, such as impacts on the natural environment and on public health. Cost-benefit analysis is the standard means to account for financial, social, and environmental benefits that accrue to society as a whole. Amounts should also be expressed in present value terms, using an appropriate discount rate. Investment would be justified with a positive net benefit figure (also sometimes called social return on investment), which is often expressed as the Benefit-Cost Ratio (BCR); a ratio greater than 1 indicates positive net benefits. At the same time, a public entity needs to ensure that a project is financially viable in order to secure and service financing.[103]

Key Role of Discount Rate

Addressing climate change requires large up-front investments in carbon reduction and resilience, both of which have long-term and somewhat uncertain benefits. Calculations of present value are therefore very sensitive to the choice of discount rate. Private investors typically apply commercial rates in the 8–12% range to future cash flows. The problem with this is that benefits arising in the distant future are close to worthless in present value terms. For example, a sum of $1 million in 60 years' time is only worth $3,000 in present value at a 10% discount rate. Public entities might consider a much lower "social discount rate," reflecting the public's view of the value of the persistence of the city long into the future.[104] (Some private investors interested in social or impact investing might also be willing to accept lower rates of return). At a 3% rate, the same $1 million is worth $170,000 today in present value terms, making investments much more worthwhile. The 2006 *Stern Review*[105] to assess the costs and benefits of action on climate change used a rate of approximately 1.4%, at which $1 million in 60 years' time is worth $435,000 today.

Investing for Resilience: The Climate Ready Boston Assessment

The CRB 2016 report is a prominent example of modeling the costs of inaction in the face of climate change and demonstrates the urgency of investing in climate resilience measures. CRB 2016 provides a useful baseline for considering the value of climate resiliency investments.

The primary economic benefits of investing in resilience are reducing future damage to buildings and infrastructure, as well as preventing the loss of business revenues and wages. The report also considered the costs of temporary housing relocation, mental stress, and lost productivity, though these were very minor. The report did not attempt to account for damage to infrastructure, the cost of loss of life or incremental healthcare, the costs of extended disruption to business, employment and supply chains, the costs of disaster recovery (aside from temporary housing),

the costs of ecological damage, or the broader costs to the region in terms of lost competitiveness. The cost estimates should therefore be considered as quite conservative.

The emerging standard approach is to model the depth of flooding expected in various areas of a city, then calculate the likely damage to buildings using a depth-damage function, which gives the expected percentage loss of value for various types of buildings for a given flood depth. The CRB 2016 report estimated losses under 3 scenarios of sea-level rise corresponding to different time periods, and for 4 flood scenarios, from a 0.1% (1 in a thousand year) flood to a 10% (1 in ten year) flood.

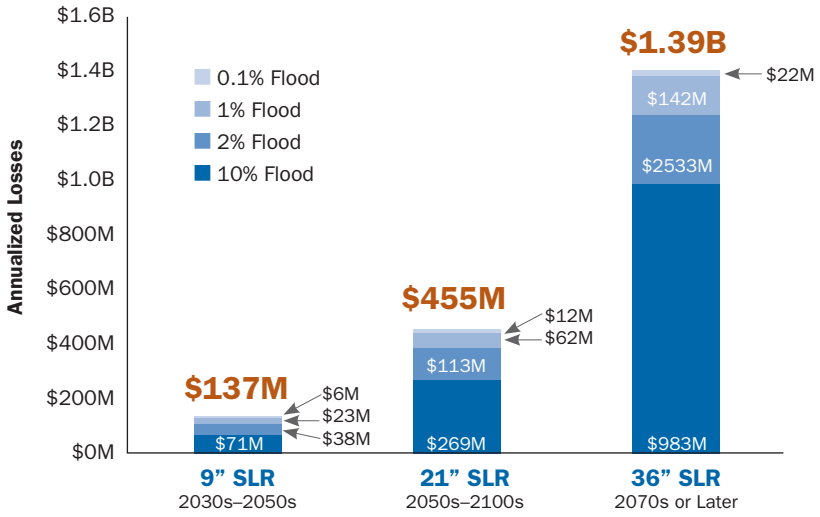
The various categories of loss considered are shown in Figure A2.

Using these numbers, the present value of the costs of doing nothing are about $10.3 billion, using a 3% discount rate and counting until 2100. Going further into the future, sea level rise would be even more severe—using an annualized cost of $2 billion a year from 2100 to 2120, the present value of costs is about $13 billion. Highlighting the sensitivity of these results to the discount rate, at a 6% discount rate the PV of the costs is only $2.7 billion to 2100, and $2.9 billion to 2120.

These numbers provide a basis for estimating the net benefits of investments in city-wide resilience projects. The forthcoming study on the feasibility of a harbor barrier will provide a more complete analysis, but the data in the CRB 2016 report provides some insight. A harbor barrier that entirely eliminated future damage would save the city about $10 billion in present value terms (counting to 2100 at the low discount rate) —it would be worth paying up to that amount to construct a barrier, because the benefit-cost ratio would be greater than 1, implying a positive net present value. A harbor-wide barrier that costs more than $10 billion, however, would yield a BCR less than 1, substantially so if higher discount rates are used. If a large scale project also protects assets in

FIGURE A1

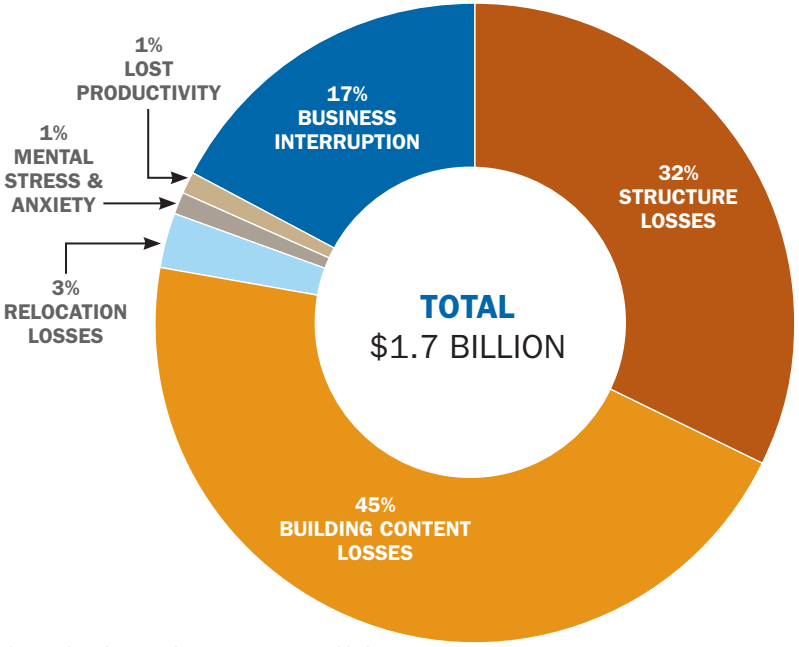
City of Boston Projected Annualized Losses



Source: City of Boston, Climate Ready Boston, 2016

FIGURE A2

City of Boston Annualized Losses: 36 inch Sea Level Rise Condition



Source: City of Boston, Climate Ready Boston, 2016

other metro-region cities such as Cambridge, then those benefits should be included as well. Other options can also be evaluated, for example, a more modest set of investments that reduce damage by 70% would be worth up to $7.2 billion, and might be more feasible. The analysis also suggests the value of delaying investment—a 10 year delay reduces the present value of the cost by 34%, in a period when the expected losses are relatively low.[106] During this time, we would resolve some of the scientific uncertainty regarding the impact of climate change on sea level rise and storm surge, and new technologies might emerge.

The RoI for resilience projects, such as green infrastructure, improves when multiple benefits are incorporated into cost-benefit analyses.

Review of other Cost-Benefit Studies

A number of studies have examined the costs and benefits of various resilience investments, such as harbor barriers, stormwater management, green infrastructure, and resilient buildings. Overall, the methodologies and assumptions differ widely and it is difficult to compare studies and draw clear conclusions. Overall, the direct financial return on resilience investments does not appear attractive in low to moderate climate scenarios, but generally turns positive under more severe scenarios of sea level rise and extreme precipitation. The discount rate also has a major impact, as discussed above, with many projects showing positive Benefit-Cost Ratios (BCR) with a 2–3% discount rate, but marginal BCRs or less than 1 with rates of 6–7%. Some studies report a positive return on investment, but the methodologies and assumptions are questionable. For example, future benefits are not discounted in some reports, and some analyses of "green buildings" count high levels of co-benefits from energy efficiency or health, which might derive from investments in other aspects of the buildings but not directly in resilience.

Harbor Barrier Studies

A 2014 study of resilience options in the New York-New Jersey harbor region calculated BCRs for several flood protection strategies under three climate scenarios.[107] The study concluded that "none of the flood protection–barrier strategies is economically attractive (BCRs less than 1) under current climate conditions or a low climate change scenario." Overall, a hybrid strategy that included more neighborhood level, small scale projects had the highest BCR ratio. In the middle climate scenario, the BCR was significantly higher than 1 with 4% discount rate, but not with a 7% rate. All the strategies were economically attractive in the high climate change scenario (rapid polar ice melt and significant increase in storm activity).

Stormwater Management and Extreme Rainfall

A 2015 study of Cambridge, Massachusetts,[108] that modeled potential extreme precipitation events concluded that damage would be over $61 million for a 100–year event in 2030 and over $232 million for a 100–year event in 2070, for all building types. To put in perspective, this was less than 1% of the total assessed value of city buildings. The study also analyzed temporary loss of employment and output from a 100–year event in 2030. 136 properties were impacted affecting between 5,530 and 8,555 employees. For every day these properties are out of service, the Cambridge economy would lose between $3.4 and $4.6 million in total output. Indirect losses, stemming from the multiplier effect of lower incomes and spending in the city, could add 50% to these figures.

A 2016 study of "smart surface" solutions to stormwater management in Washington, DC[109] concluded that "The District could reap net benefits of at least $5 billion over 40 years by widely adopting cool roofs, green roofs, solar PV, bioretention, rainwater harvesting, reflective pavements, permeable pavements, and urban trees. Benefits valued include energy cost savings, improved air quality and public health, reduced stormwater runoff, climate change mitigation, and increased resilience and employment." It should be noted that the report did not focus on damage prevented—rather, the report examined avoided stormwater fees and infrastructure costs, health, and energy. The report tallied costs of $890 million in 2015 dollars, and benefits over 40 years of $2.9 billion. The report also estimated that adoption at scale of these surface technologies could avoid about $3.1 billion in lost tourism spending, including $335 million in city tax revenue. The report emphasized that measures are complementary and provide greater resilience benefits in combination. For example, surfaces that reduce heat (green roofs or high albedo surfaces) help to cool buildings in the neighborhood, reducing air conditioning use and therefore fuel use and carbon emissions, while also increasing the efficiency of PV panels (which also provide shade to roofs).

The report emphasized that measures are complementary and provide greater resilience benefits in combination. For example, surfaces that reduce heat (green roofs or high albedo surfaces) help to cool buildings in the neighborhood, reducing air conditioning use and therefore fuel use and carbon emissions, while also increasing the efficiency of PV panels (which also provide shade to roofs).

The largest single category of benefits is reduced stormwater management expenses, which, even by itself, exceeds the cost of "smart surface" measures. Some other categories are somewhat dubious and potentially represent double counting, or awkward mixing of private and social benefits. Employment shows as a benefit, whereas economists would usually consider it as a cost, unless there is significant unemployment. "Climate

change" seems to represent the benefit of emissions reductions, but these are also counted in the energy reduction "financial incentives" figure, which represents public subsidies for emission reducing technologies. The inclusion of avoided high water fees for new impervious surfaces might represent private benefit, but not the real benefit to the city.

TABLE A2

Smart Surface Costs and Benefits for Washington, DC

Category	Present Value Over 40–Year Analysis Period (2015$)
Costs	**$890,546,000**
First cost	$583,879,000
Operations and maintenance	$206,523,000
Additional replacements	$98,600,000
Employment training	$1,546,000
Benefits	**$2,942,239,000**
Energy	$346,745,000
Financial incentives	$65,604,000
Stormwater	$1,438,893,000
Health	$524,131,000
Climate change	$454,110,000
Reduced portable water use	$15,868,000
Reduced salt use	$693,000
Employment	$112,056,000

Source: Washington DC, Achieving Urban Resilience, 2016

TABLE A3

Benefit-to-Cost Ratio Summary for Each Solution in the District

Technology	Benefit-to-Cost Ratio
Cool Roofs	7.3
Cool Roofs + Bioretention	3.4
Cool Roofs + Rainwater Harvesting	3.9
Green Roofs	2
PV (Direct Purchase)	1.8
PV (PPA)	Immediate payback/no out of pocket cost
Reflective Pavements	2.6
Permeable Pavements	14.2 (Reflects high DC water fees for new impervious surfaces)
Urban Trees	3.4

Source: Washington DC, Achieving Urban Resilience, 2016

The DC report does provide a useful breakdown of BCR ratios for different measures, which at least indicates their relative value.

New York City Department of Environmental Protection published a Cloudburst Resiliency Planning Study in early 2017, which was a cost-benefit analysis conducted by Ramboll of planning for extreme precipitation in Queens, NYC.[110] The study estimated that the Cloudburst Masterplan, designed to a 100-year storm standard, would cost approximately $330 million in PV terms, at a 7% discount rate (including operating and financing costs). Implementing the masterplan would reduce the cost of damage and lost output by 75%, or approximately $310 million in PV terms over 100 years, at the 7% discount rate. The BCR was therefore less than 1 in these narrow terms and at a relatively high discount rate. The analysis turned positive, with a BCR of 1.8, when social benefits of $290 million were included, representing avoided injuries and mental stress.

RoI on Buildings

Owners of buildings, whether private or public, have the opportunity to consider investing in measures that improve the resilience of buildings. For new buildings, resilience can often be incorporated into the overall design with only marginal impact on total building costs, generally less than 3%. Elevating buildings and moving critical equipment above the first floor are the most basic steps. The cost of not using the first floor (or only for parking etc.) can be offset by measures, for example, that compensate resilience measures with a height variance. For existing buildings, relatively low-cost measures include portable temporary flood barriers, flood proofing basement and first floor windows, installing pumps with backup power, and moving critical equipments, such as electronics, HVAC and elevator gear, to higher floors. Emergency preparedness plans should also include relatively low-cost measures for organizational recovery and continuity, such as resilient data and

communications systems, and facilities for remote and offsite work.

Experience from Hurricane Sandy in New York indicates that buildings with preparedness measures were back in service very quickly, in a matter of days, while those with critical equipment in flooded basements or data loss were out of service for weeks or even months. Expensive large-scale retrofits may be more viable when part of a larger package of upgrades and energy efficiency measures. Financing resilience becomes a bigger issue for retrofits, which require the ability to forecast and capture monetary benefits. Generally, RoI at the building level is based on private calculations of cash flows to owners, though renters/lessees also benefit, creating some split incentive issues. Anecdotal data indicates that commercial lessees are requesting climate clauses that release them from contract liability and compensate them for losses if a facility is rendered inoperable.

Buildings and infrastructure that provide critical functions and services, such as healthcare, police, fire, telecommunications and power, clearly have high value beyond the building itself, so estimates of the benefit-cost ratio should include the value of these facilities in maintaining key functions and services and accelerating recovery from disruptive events.

The main financial benefits of resilience for private building owners can include:

a. Lower insurance costs
b. Lower cost of uninsured damage and repairs
c. Lower cost of mortgage and other debt
d. Lower risk of losses due to business disruption or loss of rental income
e. Green branding and resilience awareness can generate higher rents and occupancy rates
f. Higher resale value, or at least lower risk of price decline due to rising climate awareness

TABLE A4

Benefits of Cloudburst Masterplan

Benefits	$M
Avoided risk costs	310
Physical damages	185
Output loss	125
Avoided social costs	290
Injuries	90
Mental stress and anxiety	200
Avoided environmental costs	0.02
Improved water quality	0.02
Created social values	2.5
Health benefits	0
Recreational value	1.9
Aesthetic Value	0.6
Created environmental values	0.3
Pollutant removal	0.1
Carbon sequestration	0.2

Source: New York City Department of Environmental Protection, Cloudburst Resiliency Study, 2017

Overall, there is much less experience or data on resilience investments compared with energy efficiency and clean energy upgrades, making it harder to estimate the RoI and more difficult to secure financing. Most reports and academic studies wrap up resilience with efficiency and other aspects of green buildings, which gives an indication of overall costs and benefits, but does not separate out resilience. Anecdotal evidence indicates that insurance markets and property prices do not yet fully factor in climate risk, and therefore do not provide sufficient incentives. The lack of standardized metrics for resilience also makes it difficult for investors to document and monetize the benefits. On the other hand, property developers who are pioneers in resilience and green buildings claim to generate significant premiums that justify the business model.

Summary of Evidence on Building RoI

A review of studies on green buildings by Andrea Chegut at MIT and colleagues found that new LEED certified buildings in the US cost only up to 3% more to build.[111] In Europe, a few case studies found that the cost of meeting the BREEAM 2008 certification standard was more significant, up to 37%. Chegut et al. also led a recent empirical study of 500 buildings in the UK, of which 200 were BREEAM-certified and found that the green buildings did not cost significantly more to build.[112] Design costs for green buildings were over 65% higher than for conventional buildings, but because design costs are usually only about 3% of total building costs, they have a limited impact. According to the authors, high design costs might, however, influence decisions because they are paid up-front out of developers' equity. Chegut then summarized studies of the financial benefits of green commercial buildings—rent premiums ranged from 6.5–21.5%, and property price premiums were 13–30%. Energy efficient residential buildings commanded a price premium of 2–16%. Overall, this indicates a significantly positive RoI.

One study that focused solely on resilience, by the Alabama Center for Insurance Information and Research (ACIIR), found that FORTIFIED-certified homes commanded a nearly 7% price premium.[113] The Insurance Institute for Business and Home Safety (IBHS) FORTIFIED program has developed standards for residential and commercial properties that incorporate measures to protect buildings from extreme events as well as accelerate recovery.[114] Alabama currently has the largest number of FORTIFIED certified homes, due to programs that incentivize the standard and mandate insurers to provide discounts to homes meeting the standard.[115]

The Urban Land Institute (ULI) issued a report in 2015, based on a number of case studies, which attempts to make the business case for resilience.[116] The cases are mostly new buildings and include energy efficiency and resiliency, yielding some synergies—but making it difficult to separate the costs and benefits from different elements. The largest source of cost reduction is from energy savings—for example, the Spaulding Rehabilitation Hospital in Boston, completed in 2013, included a range of resiliency and efficiency measures with incremental costs estimated at $1.5 million, yielding energy savings of about $500,000 a year. The building was designed to withstand a category 3 hurricane with winds speeds of 111 to 129 mph and storm surges between 9 and 12 feet above normal, but lower insurance or financing costs are not mentioned. ULI also reports on a mixed use residential property at 6 New Street, Boston which implemented resilient design features that the projects' insurance underwriter estimated could reduce flood loss expectancy from $10 million to $1 million dollars, potentially resulting in substantially reduced insurance premiums. The building was due to be completed in 2016, after the ULI report was prepared, and it is not clear what insurance savings were realized. Other property developers have indicated that in the absence of widely accepted standards for resiliency, insurance savings are minimal.

GREEN INFRASTRUCTURE

Natural and nature-based measures can help to protect areas from flooding due to intense precipitation or storm surge. The US Army Corps of Engineers defines natural neatures as those "created through the action of physical, biological, geologic, and chemical processes operating in nature, and include marshes, dunes and oyster reefs. Nature-based features are created by human design, engineering, and construction to mimic nature."[117] Here we refer to both as Green Infrastructure (GI) for convenience and focus on the management of coastal storm surge flooding.

Some types of natural or GI systems can lessen storm surge impacts by decreasing wave heights, building up land, or actually reducing the surge itself. Marshes, for example, help to reduce waves, but are not so effective

Flooding of the Harbor Walk in Dorchester, Boston. March 2018.

at reducing surge.[118] The benefits can be substantial. A study used dynamic modeling of coastal storm surge to model how wetlands affected flood losses to buildings from hurricane Sandy, and concluded that losses were reduced by 29 % in Maryland, but hardly at all in Connecticut.[119] Several studies note that more research on the physical and economic effectiveness of GI systems is needed, because the benefits are complex and very site specific.[120]

The overall value of GI investments is difficult to estimate because there has been little research that integrates (1) the monetary value of ecosystem services of GI aside from flood reduction (though there is a well-established literature on valuation of ecosystem services)[121] and (2) the flood management services of GI. In the USA, project evaluation by the US Army Corps of Engineers is not required to assess the benefits of GI beyond Flood Risk Reduction (FRR).[122] Co-benefits of GI such as recreation, carbon storage and sequestration, and fisheries ought to be evaluated but are rarely included in cost-benefit analyses.[123] Some research has explicitly attempted to monetize the non-flood management benefits of GI. One study of the economic value of fisheries enhancement created by oyster reef restoration estimated a net present value (NPV) of $5.6 million, without counting the risk reduction afforded by oyster reefs.[124]

Conclusions

Making a clear business case is critical to leverage private investment in resilience, and similarly, cost-benefit analysis needs to demonstrate net benefits to justify public investment. The business case for resilience, however, is not as clear as that for energy efficiency and clean energy. Existing studies indicate that incremental investments in resilient and green new buildings have a solid financial return, but that retrofits on existing buildings need to integrate energy efficiency with resilience to justify investment. Cost-benefit analyses of major infrastructure projects generally point to net benefits (benefit-cost ratios greater than 1) for medium to severe climate scenarios, and with low discount rates, but marginal or negative net benefits for nearer term, more modest climate impacts, and/or higher discount rates. More refined, comprehensive, and standardized metrics and estimation protocols would be valuable.

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