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REVIEW ARTICLE



Is coastal adaptation a public good? The financing implications of good characteristics in coastal adaptation

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Sea level rise poses a crisis for coastal communities. Many local governments have identified strategies to prepare for the impacts of sea level rise but often lack funding mechanisms. To date, the assumption that coastal adaptation is a public good has limited the tools used to finance responses to sea level rise. We argue that good characteristics - subtractability, excludability, heterogeneity, joint production, and capital intensity - combine in unique ways across adaptation strategies, and few strategies provide exclusively public goods. These good characteristics create political opportunities for application of financing mechanisms such as property taxes, district-level finance, and bonds that have been less commonly used for adaptation. Exploring the good characteristics of a particular adaptation strategy can help communities identify an appropriate and feasible mechanism for financing it.

Keywords: climate change adaptation; public goods; financing; sea level rise; coastal flooding; governance

1. Introduction

As the impacts of climate change begin to be felt across the globe, it is clear that adaptation is essential. Sea level rise, in particular, poses a crisis for many communities. In the absence of adaptation, by 2050, global annual flood losses in coastal areas may total over \$1 trillion (Hallegatte *et al.* 2013). In the face of these dire predictions, coastal communities must define who is responsible - and who will pay - for adaptation.

Numerous strategies exist to limit the consequences of sea level rise, ranging from sea walls to managed retreat. Increasingly, coastal municipalities are creating plans that assess vulnerability and propose policies to reduce the impact (Woodruff and Stults 2016; Reckien *et al.* 2014). Many more have integrated sea level rise adaptation into comprehensive, sustainability, and other planning efforts. These plans propose a wide range of strategies to address sea level rise, but often fail to discuss how these strategies will be funded (Woodruff and Stults 2016; Baker *et al.* 2012). Plans are an important first step in assessing vulnerability, building community consensus, and identifying strategies, but alone they are not sufficient to reduce vulnerability (Preston, Westaway, and Yuen 2011). To protect coastal communities from sea level rise, plans must be implemented. However, there is a significant implementation gap in climate

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change adaptation, with little action taken on the ground (Moser, Coffee, and Seville, 2017). One study found that over 80% of local governments in the United Kingdom had conducted climate risk assessments, but fewer than 40% had a plan for addressing them and none had implemented those plans (Porter, Demeritt, and Dessai 2015).

Funding is consistently cited as the primary obstacle to climate change adaptation (Carmin, Nadkarni, and Rhie 2012; Shi, Chu, and Carmin 2015; Molinaroli, Guerzoni, and Suman 2019; Baker *et al.* 2012). The cost of adaptation to sea level rise is substantial. In 2016, the United Nations Environment Program estimated that, by 2030, the global cost of adaptation could range from \$140 billion to \$300 billion annually (UNEP 2016). In Venice, €4.5 billion has already been invested in mobile tide gates (Molinaroli, Guerzoni, and Suman 2019). Adaptation costs in Miami have been estimated at \$51 billion (Molinaroli, Guerzoni, and Suman 2019).

The responsibility for funding adaptation and the financing tools available to cities vary across countries. In many countries, the national government has primary responsibility for coastal defenses, but there are often complex arrangements for sharing authority with regional and local governments. Without clear allocation of responsibility, different agencies and levels of government have incentive to shift the burden elsewhere. An analysis of OECD countries found that only five national governments have dedicated adaptation funding (OECD 2019). Because local governments are most directly engaged in responding to climate impacts, they end up bearing the costs of actions to reduce those impacts. Even in large, wealthy cities, these costs cannot be absorbed by existing budgets. For example, even though protective efforts are cost effective in Ho Chi Minh City, Vietnam because of its high vulnerability to flooding and sea level rise (Hallegatte *et al.* 2013), the city has been unable to secure financing for these investments (Hinkel *et al.* 2018).

To date, local governments have utilized a relatively narrow set of tools for financing adaptation. Adaptation is often assumed to be a public good and, consequently, best provided by government through broadly applied taxes or fees (Termeer *et al.* 2011; Boyer, Meinzer, and Bilich 2017; Tompkins and Eakin 2012; Mees, Driessen, and Runhaar 2012; Bisaro and Hinkel 2018). We argue that this type of broad-brush treatment ignores the wide variation in adaptation strategies. Many approaches that communities are taking to protect themselves from coastal flooding do not meet the classic definition of pure public goods, but entail collective action problems of various types. The misalignment of financing tool and good characteristics can result in political opposition to adaptation. More explicitly recognizing the characteristics of goods and services produced by adaptation strategies can help identify private incentives for adaptation investment and provide insight into a broader set of financing options.

Financing tools determine how adaptation costs will be distributed across the community and over time (Wamsler and Riggers 2018). A growing literature examines the roles and motivations of private actors implementing adaptation strategies (Tompkins and Eakin 2012; Mees, Driessen, and Runhaar 2012; Hegger *et al.* 2017; Bisaro and Hinkel 2016; Wamsler and Riggers 2018; Mees 2017). Insufficient attention has been dedicated to identifying the private beneficiaries of publicly funded adaptation and the ways that private benefits may boost political support for adaptation investment by local governments (Tompkins and Eakin 2012; Mees, Driessen, and Runhaar 2012; Wamsler and Riggers 2018). This information is critical for designing feasible and effective policy instruments and, in particular, financial structures that advance adaptation. General guides to the tools available for leveraging capital for adaptation

investment (Brugmann 2012; Levy and Herst 2018) do not link the tools to specific adaptation strategies, which vary widely in their distributions of benefits and burdens. The characteristics of particular adaptation strategies do not only generate incentives for private provision; they also create constraints and opportunities for the use of different public finance instruments.

This paper contributes to the adaptation governance literature by drawing links between coastal adaptation strategies and local mechanisms to finance those strategies. We build our argument by drawing on an extensive review of the adaptation, public policy, and financing literatures and provide illustrative examples from cases covered in media reports and the grey literature. By exploring the complex features of adaptation goods, we identify opportunities for using a broader set of financing tools for adaptation investment and encourage their adoption. Our emphasis is on funding needed to implement physical and regulatory responses to sea level rise, recognizing that these responses are often part of broader visioning and planning processes for a community.

In the next section, we introduce five good characteristics - *excludability*, *subtractability*, *heterogeneity*, *joint production*, and *capital intensity* - strategies that we explore throughout the paper. We then describe the specific types of sea level rise adaptation - avoidance, retreat, accommodation, and protection. Then, we categorize sea level rise strategies based on their good characteristics and discuss the implications for generating collective action for climate adaptation. Drawing on the good characteristics of the adaptation strategies, we align each adaptation strategy with different types of financing instruments. We then examine the constraints local governments face when selecting financing tools for adaptation. Finally, we conclude with recommendations for practitioners and researchers.

2. Coastal adaptation as a public good

Classic categorization of economic goods is based on *subtractability* (or rivalry), defined as the extent to which one's consumption of the good limits others' ability to consume it, and *excludability*, the ease of restricting access to the good (Ostrom 2005). These characteristics distinguish four types of goods: (1) *private goods* for which one person's consumption limits the availability to others, but exclusion is relatively easy; (2) *common-pool resources* that also have high subtractability, but exclusion is difficult; (3) *toll goods* (also referred to as club goods) for which subtractability is minimal, but exclusion is easy; and (4) *public goods* for which consumption is not rival and exclusion is difficult.

Many aspects of coastal adaptation have public good characteristics (Termeer *et al.* 2011; Bisaro and Hinkel 2018). Boyer, Meinzer, and Bilich (2017) argue that the widespread, transboundary consequences of sea level rise and other climate change impacts pushes adaptation towards the public goods end of the conceptual continuum. This argument mirrors the Berke and Lyles (2013) classification of climate change as a "public risk," one that "is mass-produced, broadly distributed, temporally remote, and largely outside the individual risk bearer's direct understanding and control" (190). Furthermore, adaptation often addresses threats to public goods, such as public health and safety (Tompkins and Eakin 2012; Mees, Driessen, and Runhaar 2012).

Boyer, Meinzer, and Bilich (2017), however, recognize that there are significant "impurities" in adaptation, since climate change impacts are not equally distributed along the coast. The fact that some communities and some individuals will be more

heavily affected narrows the “public” nature of climate impacts. The unequal distribution of impacts means that the benefits of adaptation are also unequal. In classifying adaptation goods, we must therefore consider *heterogeneity* of benefits.

In addition, many coastal adaptation strategies *jointly produce* an adaptation benefit along with some other type of good or co-benefit. When coastal adaptation strategies produce both a public and a private good, they can be treated as impure public goods (Cornes and Sandler 1996; Kotchen 2006). For example, beach nourishment may provide protection as well as tourism benefits. Finally, we consider *capital intensity* of coastal adaptation, or whether the provision of the good must surpass some threshold level before the group enjoys benefits (Sandler 2015). Again, in the case of beach nourishment, an entire beach must be replenished to a certain threshold before benefits accrue.

These five good characteristics - subtractability, excludability, heterogeneity, joint production, and capital intensity - combine in unique ways across coastal adaptation strategies. Communities may consider diverse strategies ranging from measures to elevate individual homes to large-scale protection projects such as sea walls and beach nourishment. Recognizing the good characteristics associated with these different strategies will help identify policy and financial tools that align public and private interests to advance adaptation (Bisaro and Hinkel 2018).

3. Coastal adaptation strategies

Adaptation strategies in the face of sea level rise are typically classified into three categories: *accommodation*, *protection*, and *retreat* (Moser, Jeffress Williams, and Boesch 2012; Butler, Deyle, and Mutnansky 2016; IPCC, 1990). We also consider a fourth category: *avoidance*.

Accommodation measures do not prevent floodwaters from entering a community, but instead aim to reduce the negative impacts of flooding. Accommodation measures include efforts to elevate structures and alterations to building codes to improve flood performance. Accommodation measures may be individually (elevating home) or collectively (stormwater upgrades) produced. Local governments are well equipped to adopt and implement accommodation strategies since many of these approaches have been used for decades to reduce the risk of flooding (Butler, Deyle, and Mutnansky 2016). Sahin *et al.* (2013) found that local politicians generally prefer accommodation measures over other adaptation strategies. Maintaining the tax base may also explain the preference for these measures (FEMA 2017; Seibert 2001).

Protection includes hardened infrastructure such as seawalls, as well as “soft” structural protection measures such as beach nourishment. Along highly developed shorelines, structural protection has historically been the most prevalent approach to prevent coastal flooding (Moser, Jeffress Williams, and Boesch 2012; National Research Council 2014). Depending on the spatial scale and degree of protection, protection measures may be individually or collectively produced.

Retreat (sometimes called *abandonment*) removes development from areas at risk of inundation through mechanisms such as buyouts (Zavar 2015). Retreating from hazardous areas eliminates risk rather than reducing it (Butler, Deyle, and Mutnansky 2016), making it an attractive option when considering longer timeframes (Hino, Field, and Mach 2017). However, retreat has high financial and social costs for property

owners (FEMA 2007). It can also have severe implications for the community's tax roll. The loss of tax base, as well as political and legal opposition, have limited the adoption of retreat policies (Butler, Deyle, and Mutnansky 2016; National Research Council 2014). Signals of retreat, or even messages that community size or composition may change, can challenge community identity and self-definition.

Avoidance proactively minimizes flood risk by limiting future development in current and projected flood hazard zones and protecting ecosystems that are critical to flood mitigation. Benefits of *avoidance* are similar to *retreat*; however, the financial and social costs for both land owners and the community are generally much lower than for retreat measures. Still, in the absence of major flood damage, communities often lack political will to avoid hazardous areas (Birkland et al. 2003). Moreover, gathering precise and reliable information about the likely effectiveness of *avoidance* measures may be more difficult than for other adaptation strategies. These barriers, combined with the absence of adequate funding incentives that encourage proactive adaptation (Smith 2014), result in very few communities undertaking *avoidance* strategies (Christin and Kline 2017).

4. Good characteristics and coastal adaptation

As Table 1 demonstrates, local adaptation to coastal flooding encompasses a wide range of strategies that promote the provision of different types of goods. Careful consideration of a good's characteristics can help communities identify funding strategies that satisfy a project's financial demands and maximize the potential for political support. In Table 2, we outline those characteristics and how they correspond to coastal adaptation approaches. In coding good characteristics, we treat the adaptation approaches in terms of their collective provision at the community level - for example, elevation of multiple homes, rather than elevation of an individual home. Because each approach encompasses a variety of different strategies, and the strategies themselves exhibit wide variation, our coding is intended to be illustrative and not perfectly applicable in every case.

Accommodation strategies designed to reduce the vulnerability of existing privately owned residences and businesses are providing private goods: elevating one's home does not prevent a neighbor from doing the same (low *subtractability*), but the neighbor doesn't benefit from the action (high *excludability*). In contrast, accommodation that focuses on retrofit and enhancement of existing public facilities typically would fall under the category of public goods, because the benefits are widely shared and do not diminish with consumption. Most avoidance and retreat strategies that are oriented toward protecting natural resources and encouraging development patterns that avoid future harm also have public good characteristics. Protection strategies designed to reduce flooding from changing storm behavior and sea level rise are often non-*subtractable* but spatially uneven, producing benefits that are *excludable*, depending on the design of the project. Under those circumstances, adaptation can be considered a club good.

Excludability is the dominant characteristic of interest in considering the feasibility of private provision of adaptation. If a good is not *excludable*, users have an incentive to free ride on the contributions of others. By the simplest application of economic theory, we would expect protection and accommodation strategies to be self-supplied

Table 1. Adapted from Butler, Deyle, and Mutnansky (2016), provides an overview of major land-use related adaptation planning strategies in the face of sea level rise.

Adaptation approach	Strategies	Description
Accommodation Alter existing assets to reduce vulnerability	Elevate	Raising the first floor of structures above current design flood elevations
	Flood proof	Changes to structures to reduce or eliminate flood damage
	Storm water system enhancements	Structures to counteract reduced storm water head differentials and backflow into storm water discharge pipes, e.g. tide gates, storm water discharge pumps
	Retrofit	Retrofit public facilities and infrastructure to enable continued functioning
Protection Hard or soft engineering works designed to prevent flooding from sea level rise	Shoreline armoring	Seawalls, bulkheads, revetments to protect structures from higher flood elevations
	Green infrastructure for shoreline stabilization	Vegetated buffers, living shorelines, plants, reefs, restored natural features
	Beach and dune nourishment	Beach and dune building and re-nourishment projects to counteract erosion
	Flood works	Dams and levees to protect vulnerable assets
Retreat Relocating existing assets to places less likely to be exposed to sea level rise	Post-disaster down zoning	Down zone built-out land in storm surge flood zones to prohibit redevelopment of properties damaged by flooding
	Post-disaster relocation or acquisition	Relocate public facilities and infrastructures in anticipation of advancing hazards
	Rolling easements	Prohibit shoreline armoring and require that structures be moved landward or removed when mean high water line reaches a specified threshold
Avoidance Prevent development in risky locations and protect natural resources	Zoning	Limit development of land at risk of storm surge, flooding, and future inundation from sea level rise
	Conservation	Protect sensitive coastal ecosystems through acquisition, easements, or zoning
	Setbacks or buffer zones	Setbacks or buffers from the shoreline to avoid sea level rise damage
	Public facilities	Avoid expansion of public facilities such as roads, sewers, and water into hazard areas

Table 2. Public good characteristics for different sea level rise adaptation approaches.

	Accommodation	Protection	Retreat	Avoidance
Subtractable	Yes	No	No	No
Excludable	Yes	Yes	No	No
Heterogeneous benefits	Yes	Yes	Yes	No
Joint production	No	Yes	Yes	Yes
Capital intensive	No	Yes	Yes	No

by the households and individuals that benefit from them, while retreat and avoidance would require public intervention.

Even where goods are *excludable*, however, other good characteristics such as *heterogeneity* can interfere with private production. Adaptation strategies that provide private goods may have high *heterogeneity* in impact, delivering different levels of benefit across the community according to individuals' consumption of them. This *heterogeneity* is most pronounced for protection measures, whose effectiveness in risk reduction is highly spatially dependent. Oceanfront homes and businesses, for example, reap more protective benefit from nourishment and shoreline armoring than do inland properties (Gopalakrishnan *et al.* 2016). Retreat strategies also display *heterogeneity* in the benefits of good production, as the choice to acquire or re-zone some properties and not others imposes differential costs and benefits across property owners (Kihlslinger *et al.* 2017, 15). Avoidance, in contrast, disperses costs more evenly.

Heterogeneity of benefits influences group organization (Olson 1965; Adger *et al.* 2009; Bisaro and Hinkel 2016). Where individual property owners will experience a high ratio of benefits relative to cost, they have incentive to self-provide the adaptation measure, or to give political support for its public provision. Those who experience smaller relative benefits may oppose public provision if they perceive that the distribution of benefits is unfair. Strategies that deliver *heterogeneous* benefits may, therefore, spark more political division than those with benefits that are widespread, but at the same time they can create constituencies for whom the policy is salient (Bisaro and Hinkel 2016). The *heterogeneity* of benefits is particularly important in distinguishing between avoidance strategies that take on fairly typical public good characteristics and retreat strategies whose production at the community level is likely to entail concentrated costs or benefits for particular property owners.

Another feature relevant for the choice of financing mechanism is *joint production*, also referred to in the adaptation literature as provision of co-benefits. Some coastal adaptation strategies bundle risk reduction along with a co-benefit that is not adaptation-related, such as ecosystem restoration, improved water quality, or recreation and scenic amenities. The two goods may have different good characteristics. Depending on the characteristics and value of the bundled goods, the co-benefits can create incentives for provision of adaptation. Recognizing joint production is particularly important when one of the goods is a private good and the other is public. Finance mechanisms that take advantage of private incentives to produce private goods could help mobilize more resources toward joint provision of public goods that have broadly distributed benefits.

Finally, the *capital intensity* of an adaptation strategy can shape incentives for private provision and influence financial tools available. For most accommodation strategies, incremental provision of the good offers incremental benefit; any contribution of

a retrofitted facility adds a marginal benefit to collective risk reduction. Although elevation or retrofit of an existing privately owned structure may be very costly to the property owner, at the community level, the accommodation of individual properties is an incremental strategy that does not entail high sunk costs. Accommodation of public facilities is more capital-intensive (stormwater system upgrades), and the same is true for most protection strategies. From the standpoint of collective action, capital intensity means that provision of the good must surpass some threshold level before the group enjoys benefits (Sandler 2015). In the absence of government authority, it can be difficult to secure and coordinate the level of participation necessary to fund capital-intensive goods.

Taken together, *subtractability*, *excludability*, *heterogeneity of benefits*, *joint production*, and *capital intensity* contribute to the likelihood of voluntary collective action to implement each strategy. Most of the strategies entail collective action problems severe enough to rule out voluntary provision and to necessitate public policy interventions. The characteristics we have outlined also contribute to the applicability and political viability of different types of public finance tools.

5. Financing coastal adaptation

Recognizing the diverse characteristics of adaptation goods can promote consideration of a broader set of tools to finance adaptation. Local governments that have begun implementing meaningful measures to reduce their vulnerability to sea level rise are experimenting with various finance instruments to fund their efforts, and experts in the fields of finance and adaptation have proposed additional tools (Levy and Herst 2018; US EPA 2014).

A good match between adaptation strategy and financial tool can increase the overall supply of adaptation goods by taking advantage of existing incentives and raising revenue from sources most willing to pay for the benefits of an adaptation strategy. Communities seeking to mitigate the effects of coastal flooding, therefore, need to make choices not only about which adaptation approach to take, but also about how to pay for it. A mismatch between who benefits from an adaptation strategy and those who will fund it raises concerns about fairness. Fairness means that the cost burden reflects the benefits provided, while equity means that the cost burden reflects the ability to pay. Both must be considered in designing financial tools.

We consider how the good characteristics associated with the four categories of sea level rise adaptation align with some of the dominant models proposed for financing adaptation, especially property taxes, designated fees, district-level finance, building-level finance, and bonds. Our emphasis is on tools and instruments generally available to municipalities across democratic countries, recognizing that legal and administrative constraints on using these tools vary widely. Broad discussion of local financial tools is nonetheless worthwhile, as broader trends toward decentralization combine with rising costs of sea level rise to leave municipalities shouldering a growing share of the costs of adaptation (Baker *et al.* 2012; Granberg and Elander 2007). Our examples draw heavily from the United States, where subnational spending as a percentage of total public sector expenditure is relatively high when compared internationally, offering more opportunity for creative local financing (OECD and UCLG 2016).

5.1. *Financing accommodation strategies*

Delivering mostly private goods that reduce the vulnerability of individual properties, accommodation strategies are most commonly provided by property owners who have incentive to make investments that protect the value of their assets. Yet various forms of market failures - inadequate information about climate-related risk, high discount rates that fail to account for long-term benefits of adaptation, and perverse incentives created by insurance and federal disaster aid policies - contribute to underinvestment in accommodation by private actors (Mees, Driessen, and Runhaar 2012; Mees 2017). The broader public experiences this underinvestment in the form of insurance and disaster aid payouts, public safety risks from damaged structures, and deterioration of the physical and social infrastructure in communities.

Local governments have an interest in boosting investment to reduce the vulnerability of private structures beyond what property owners might do voluntarily. Incentives have traditionally been the most common approach to motivate greater private investment in accommodation (Wamsler and Raggars 2018). An alternative strategy for promoting private accommodation is through loan programs that reduce the cost of borrowing for homeowners and businesses. Loans are intended to help private actors who are hindered by a lack of financial capacity to undertake retrofits that make sense economically. Modeled after state and local loan programs to promote energy efficiency improvements, adaptation loans could be bond-financed and require little ongoing public investment over the long term.

Another strategy that could be applied to private sea level rise accommodation is building-level financing secured by a voluntary lien on a property that is then paid off over time through property tax assessments (French *et al.* 2017; Kunreuther and Michel-Kerjan 2011; Reed 2018). Property Assessed Clean Energy (PACE) programs, which are widespread at the US state and local levels to improve energy efficiency, hinge on the increased property value associated with lower energy costs. For adaptation, reduced flood insurance premiums could create the value to finance improvements. For example, in Massachusetts, one foot of elevation above legally mandated height has been estimated to produce 41% annual savings in insurance premiums and \$15,060 savings over a 30-year mortgage (Shaw 2009). San Francisco now allows Property Assessed Clean Energy (PACE) to be used for seismic resilience measures (Levy and Herst 2018); this type of program could be extended to flooding and sea level rise measures. Loans and building-level finance programs are well-suited for catalyzing property owners' incentives to self-supply private accommodation goods, but their high administrative costs may limit their adoption at the local level only to the largest cities.

Moving to accommodation strategies for public facilities, the capital intensity of retrofit projects and public ownership of existing facilities place these measures as decidedly government responsibilities. Local governments typically fund major capital-intensive infrastructure improvements through borrowing, and they are likely to do the same for many public facilities accommodation projects. Borrowing through bonds or other instruments allow localities to spread costs of a project over time, but they still need to be secured against a revenue stream.

Where bonds are secured by property taxes or other general revenue streams, projects must compete with other local priorities for a share of government spending. This competition among spending priorities can stand in the way of accommodation investment, especially if borrowing requires voter approval. In Miami, Florida, half of a

recently issued \$400 million general obligation bond is dedicated to pay for water pumping stations, upgrades to the drainage and sewage systems, and other sea level rise adaptation projects (Smiley 2017). When the measure went in front of voters in 2017, it drew opposition from labor unions concerned about pension funding and received support from a minority of candidates running for local office that year. The measure ultimately passed, but ballot language pledged that the city would take on new debt only as it retired existing debt, producing no increase in the city's tax rate (Smiley 2017). Many cities would not be in a financial position to make that commitment.

Decision makers can avoid a public vote and tradeoffs among spending priorities by securing a bond or loan with a dedicated revenue stream. Several Florida communities have turned to stormwater fees to back bonds dedicated to reducing flood-related risk (Weiss 2016; Wallman 2017). Stormwater fees have also been adopted in Australia, Brazil, Canada, France, Germany, and South Africa (Tasca, Assunção, and Finotti 2018). Like property taxes, stormwater fees broadly distribute costs, and in some contexts they may apply even more broadly due to non-profit status or incentive packages that create exemptions from property taxation (Levy and Herst 2018). They have the added advantage of capturing heterogeneity in contribution to flooding problems by tying fees to a property's impervious surface area. Alternatively, fee levels can be tied to a project's benefits. For example, stormwater fees to secure a bond for road elevations in the Florida community of Fort Lauderdale are based on the traffic that a property generates (Wallman 2017).

Cities may also consider resilience fees or insurance-based fees to secure bonds. As with stormwater fees, basing fees on a measure of resilience or insurance premiums provides a new revenue stream while creating a market signal for developers to avoid high-risk areas or to invest in measures that reduce risks (Levy and Herst 2018). For example, Miami-Dade County has proposed fees on new development in sensitive areas to fund infrastructure improvements (Fabris 2016).

5.2. Financing protection strategies

Protection measures such as shoreline armoring and stabilization, beach nourishment, and flood works are club goods, and the ability to define boundaries around these projects provides an incentive for private actors to self-organize. In Selsey, a town on the south coast of England, a privately owned vacation resort dedicated approximately £15 million to the construction of two breakwaters and beach nourishment (Paterson *et al.* 2017; Paterson and Pelling 2017). However, the capital intensity of most permanent protection measures makes it difficult to self-finance them without access to instruments of public authority. Long-term borrowing requires the backing of a formal organization. Under some circumstances, a homeowner association or community development corporation can fill that role, but participation from local government offers readily available mechanisms for enforcing commitments as well as the opportunity to access tax-exempt government bonds.

Politically, *heterogeneity* of potential benefits from a protection strategy could help create a constituency of residents or businesses who have a concentrated interest in the policy and will advocate for its enactment, but *heterogeneity* also raises concerns about fairness. If the protection strategy involves joint production of another public good such as wider beaches, this can help ameliorate fairness concerns and attract wider (though probably shallow) support for the policy, especially with the use of a finance

tool that captures the heterogeneous value of risk reduction that the project provides (Merrill *et al.* 2018).

Protection therefore lends itself to district-level finance tools. Numerous mechanisms are available to capture value from targeted areas that disproportionately benefit from publicly financed adaptation. Most promising are special assessment districts that can finance the cost of long-lived public improvements by spreading the burden for repayment among specific properties, typically by increasing property tax. In an effort to increase fairness in protection costs, the Wellington region council in New Zealand considered redistributing the cost of flood protection so that areas at greater risk paid higher property taxes (George 2018a). This initiative was ultimately rejected due to outcry from residents who faced increased rates, but increasing fairness continues to be a goal of the regional council (George 2018b). Special assessment districts are becoming a common way to finance beach nourishment projects along the US east coast. Mullin, Smith, and McNamara (2019), for example, found that funding for nourishment projects can be increased by charging oceanfront property owners, who benefit the most, higher tax rates. This study suggests that accounting for unequal benefits of an adaptation good could facilitate greater investment in good production.

Cost recovery is another tool to recoup the cost of neighbourhood-scale investments. In the United States, this typically takes the form of tax increment financing (TIF) in which initial investments are paid by future increases in property tax revenues. Since TIF requires more certainty about the real estate value impacts of an adaptation project, it may require bundling adaptation with value-enhancing development strategies (Levy and Herst 2018). Bundling adaptation with value-enhancing development strategies is central to local adaptation in the Netherlands, where municipalities use a public land development model (Root, Van Der Krabben, and Spit 2015). Under this model, municipalities play a major role in land development processes and utilize revenues from selling lots to developers to pay for public infrastructure and services (Van der Krabben and Jacobs 2013). In 2008, municipalities were granted the power to raise costs to pay for adaptation and other public investments; however, municipalities continue to feel pressure to demonstrate the market value of these investments (Root, Van Der Krabben, and Spit 2015). Selsey is experimenting with a similar approach at the regional scale. To help fund the £30 million update and maintenance of the coastal defences, they created a community-owned trust that utilizes profits from regeneration projects for coastal defence (Selsey Coastal Trust 2011).

Even where heterogeneity exists in the protective benefits of an adaptation project, the joint production of a co-benefit that is widely shared may motivate application of a broader-based finance tool. As an example, San Francisco is planning a \$350 million general obligation bond to begin fortifying the 3-mile seawall that protects its iconic waterfront area. The working group assigned to recommend funding strategies prioritized general obligation bonds, repaid from property taxes, because of the broad tourism and transportation benefits the seawall provides, even though the narrow geographic boundaries of the project require the bond to be approved with a two-thirds supermajority citywide vote. The city is layering the general obligation bond with a targeted Community Facilities District, which will finance about \$100 million of the seawall upgrades by imposing a special tax on waterfront property owners and businesses that will benefit most from the project (Seawall Finance Work Group 2017).

Where the co-benefits of an adaptation project have tourism value, local decision makers might consider a sales or occupancy tax to capture revenue from visitors who

enjoy that value (Lee 2014; Moffat and Nichol Inc. 2016). In Florida, local hotel room taxes long have been an important source of financing for beach nourishment (Garcia 2016). However, sales and occupancy taxes have often met with local resistance (Lay 2014; Seawall Finance Work Group 2017). Opposition may center on the regressive impact of the tax, or its potential to divert mobile visitor and sales revenue to neighboring communities. Because sales and occupancy tax increases typically require approval from voters or the state, opposition from the public - or from those who would visit coastal communities - can be an important constraint.

5.3. *Financing avoidance strategies*

Many avoidance measures are essentially regulatory in nature. Local governments may use zoning and setbacks to minimize population and property exposure to flood hazard (Grannis 2011), development ordinances to set aside a fraction of new developments for open space, and transfer of development rights to avoid hazardous areas. But avoidance can also take the form of investment, mostly through acquisition of land and easements or restoration efforts that provide natural hazard protection against erosion and floods.

As more purely public goods, avoidance strategies have benefits that tend to be broadly distributed, so these along with their jointly produced benefits like water quality and ecosystem protection do not create constituencies who benefit disproportionately from public investment. Thus, targeted finance tools that can be used to leverage private interest in protection investments offer less promise here. The challenge for local decision makers is to build public support for investment using broader-based tools such as stormwater fees or property, sales, or occupancy taxes, the use of which puts adaptation into competition with other local spending priorities.

Avoidance strategies may attract opposition from developers, real estate interests, and others who experience concentrated costs from reducing the supply of developable land. In North Carolina, coastal development interests successfully lobbied the state legislature in 2012 to limit the use of scientific sea level rise rates for state regulatory purposes (Bulla, Craig, and Steelman 2017). Regulatory and financing tools that protect development interests, such as a transfer of development rights program or fee structures that include incentives for private action, may help reduce this opposition. In contrast, environmental groups and fishing and recreational interests can be important constituencies advocating for investment in avoidance measures (Kochnowar, Reddy, and Flick 2015). In some cases, mitigation banks that preserve, enhance, restore or create wetlands or coastal habitat to offset adverse impacts to similar ecosystems can provide external finance for accommodation. Innovative finance tools such as environmental impact bonds may also be a viable way to encourage private investment, especially for large avoidance projects where local asset owners such as utilities, port owners, or oil and gas companies have an interest in maintaining green infrastructure to reduce their flood damage vulnerability (Environmental Defense Fund and Quantified Ventures 2018).

5.4. *Financing retreat strategies*

Retreat differs from avoidance in the very high *heterogeneity* of impact from buyout programs and other efforts to relocate people and assets to areas with lower flood risk.

In some cases, this *heterogeneity* can promote self-organization, as in the case of Oakwood Beach, a neighborhood on Staten Island in New York City where residents organized to advocate for a buyout program. Having previously experienced several major flood events, property owners organized after Hurricane Sandy to map the targeted buyout areas and build community support. In response to this local demand, the state of New York launched a buyout program that had widespread participation (Freudenberg *et al.* 2016).

That same *heterogeneity* in impact can also produce opposition to retreat, however, and pose an obstacle to financing these measures locally. It is more common for affected property owners to oppose relocation than to seek out the opportunity, as they did in Oakwood Beach. *Heterogeneity* limits finance options, as the broader community may perceive it as unfair if locally generated tax or fee revenues get used to compensate oceanfront property owners, especially if the owners are wealthy non-residents.

The most promising opportunities for financing retreat may lie in leveraging the *heterogeneity* of the strategy's benefits. Effective management and maintenance of acquired areas can increase the value of other properties, helping to ameliorate the tax base harm of property losses. Second-row properties become oceanfront, and properties adjacent to parks and open space also enjoy increased value (Irwin 2002). District-level tools such as TIF could therefore be applied for retreat, although the equity and fairness implications of generating revenue from some community members for distribution to others remain complex. Local financing for retreat would likely only be feasible as part of a larger package of adaptation measures. Overall, managing retreat requires leadership and support from local governments, who will be the ultimate stewards of vacated properties.

Retreat is also *capital-intensive*, because acquiring properties in clusters to create a natural buffer is more effective for reducing future risk than a piecemeal approach (Siders 2013). As a result, nearly all US programs for acquiring flood-prone properties have been funded at the federal or state level (Siders 2013; Kihlslinger *et al.* 2017; Freudenberg *et al.* 2016). In Matata, New Zealand, the cost of managed retreat for 34 properties is being shared by the federal, regional, and local government (Whakatane District Council 2019). In the United States, a few localities experiencing riverine flood risk have developed local funding mechanisms to complement state and federal funding: Morris County, New Jersey generates the revenue from property taxes, while Tulsa, Oklahoma and Charlotte, North Carolina draw on stormwater fees (Kihlslinger *et al.* 2017). There has been limited uptake for local funding of retreat in coastal communities, however, where the high and location-specific amenity value of oceanfront living increases property owner resistance to retreat, and flood-prone high-value properties are likely to be an important part of the community's tax base (Spoto 2017).

6. Contextual constraints to coastal adaptation

Recognizing the good characteristics of different adaptation strategies can help communities identify appropriate and politically acceptable financial instruments, especially in settings with strong electoral accountability. In Dare County, North Carolina, an 8-year, 1% sales tax increase to fund beach nourishment was met with public outcry. The tax was repealed with 78% of the vote (Lay 2014). Subsequently, several towns in Dare County moved forward with their own nourishment projects, funded with

property tax increases that have differential oceanfront rates. With differential tax rates, oceanfront property owners who benefit the most from beach nourishment projects also pay the most, making it politically more acceptable than a sales tax that distributes costs more evenly.

Particular characteristics of a community can shape support for different financial tools. A community's economic composition presents opportunities and constraints. In many coastal settings, tourism is the primary industry and could offer revenue sources. Utilizing these sources will be most politically feasible if adaptation measures offer jointly produced benefits, such as wider beaches, that boost or protect these industries. However, shifting adaptation costs to visitors may push tourism to neighboring communities.

Continuing with the example of differential property taxes to fund beach nourishment, the extent to which oceanfront property owners absorb project costs depends on the proportion of oceanfront properties and the values of those properties compared to inland properties (Mullin, Smith, and McNamara 2019). Across different types of adaptation investments, development patterns, property values, and extent of hazard zones all combine with project design to determine the fairness and equity of different financial tools. These relationships may change over time as sea level rise differentially affects property values (Keenan, Hill, and Gumber 2018; Bernstein, Gustafson, and Lewis 2019).

Climate change will disproportionately affect disadvantaged communities, and adaptation could further exacerbate these inequalities (Shi *et al.* 2016; Anguelovski *et al.* 2016; Levy and Herst 2018). For example, retreat efforts that target low-income residents in high-risk areas echo mid-twentieth century urban renewal projects that displaced neighborhoods and aggravated racial and economic segregation (Kusnetz 2018). Accommodation and protection strategies that increase property prices and encourage new development can also catalyze displacement (Levy and Herst 2018). Affordable housing provision, rent control, land trusts and other anti-displacement measures may need to be implemented in conjunction with adaptation. Los Angeles is working with community partners to increase access to affordable housing along the Los Angeles River to ensure that environmental improvements do not contribute to displacement (Christensen 2018). The goal of equity, however, can conflict with the goal of fairness. Tools such as district-level finance and differential fees promote fairness by directly tying costs to benefit, but they pose equity concerns for high-risk, low-income areas.

Inequities exist within communities and across communities. It is difficult for all communities to self-finance capital-intensive strategies such as relocation and large-scale protection projects, but small and financially distressed communities face the greatest challenge. Small communities, by definition, have a smaller tax base for leverage and may also lack administrative capacity to implement more complex financial instruments such as loan programs. Similarly, financially distressed communities will have a limited tax base and confront lower bond ratings that increase interest rates, making bonds less attractive.

Small, financially distressed cities may also be unwilling to implement adaptation measures that reduce their competitiveness for new development. For example, new stormwater fees in Chester, Pennsylvania, a financially-distressed city, faced significant opposition due to concerns that the fees could "hinder economic development" (Ainsworth 2018). New fees may limit the city's ability to expand its tax base. In addition, adaptation has to compete with other priorities and spending initiatives, making

investments in adaptation more difficult to justify. In Chester, balancing the general fund and making payments on outstanding debts are the priority (Ainsworth 2018).

There are examples of small, financially distressed communities mobilizing to support adaptation investments. Residents in Gulfport, Mississippi diverted proposed real-estate development along the ecologically critical Turkey Creek that would have increased flood vulnerability. Strong leadership, an invested community, and funding from state agencies and environmental groups helped this historically low-income African American community acquire and donate the land along Turkey Creek to the Land Trust for the Mississippi Coastal Plain (Zaitchik 2015; Land Trust for the Mississippi Coastal Plain 2008). In this case and others, however, success was dependent on external funding support.

It is also important to note that not all municipalities have the same legal authority to adopt and implement the financial tools discussed. Local finance rules vary widely across countries and legal contexts. The complex configuration of agencies involved in coastal planning can further complicate efforts on finance adaptation.

7. Discussion/conclusion

How can fiscally constrained coastal communities motivate higher levels of public investment in adaptation? We argue that the diverse good characteristics of strategies to address sea level rise create opportunities for using a broader set of financial tools than local officials might typically consider. The characteristics of adaptation goods shape the feasibility of raising revenue with different tools as well as the political incentive structure for local decision makers. For example, the heterogeneous benefits of protection measures may make taxes and fees that broadly distribute costs politically infeasible and encourage the use of district-level financing.

We encourage practitioners to consider the good characteristics of adaptation strategies to determine the best financing tool to achieve their adaptation goals. As demonstrated in the cases we have described, creative approaches are available that take advantage of the value adaptation measures produced. In addition, practitioners should consider layering multiple financing mechanisms to create robust adaptation programs. In San Francisco, for example, general obligation bonds and district-level financing complemented each other to pay for large investments (Levy and Herst 2018). Utilizing multiple financing mechanisms can also help to address tensions that might exist between fairness and equity. Communities may also bundle adaptation strategies to take advantage of the multiple types of goods provided. Finally, financing tools should provide a strong market signal to reduce vulnerability.

We have provided examples from news outlets to support our theoretical arguments about the good characteristics and the available financial tools available for different adaptation strategies, but further research is needed on this topic. In particular, studies on the willingness to pay for adaptation investments under different financing schemes and political acceptance of different financing tools is needed. As more coastal communities invest in adaptation, in depth case studies would further elucidate the opportunities and constraints for different financing approaches. Finally, more work is needed on how financing mechanisms could better capture and leverage the value of adaptation. This requires a better understanding of avoided costs, impacts on property values, actuarial risk, and resilience metrics.

As more communities confront sea level rise, it is critical that local governments move from creating plans that lack a meaningful funding mechanism to carefully pairing strategies and financing mechanisms. The good characteristics of different adaptation strategies and community context create opportunities and constraints for different financing mechanisms.

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