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Abstract: In this paper we develop methods for identifying local business and government vulnerabilities to sea-level rise and the natural hazards associated with it. Unlike the fairly large literature on measuring social vulnerability to natural hazards, there are very few papers that discuss methods for measuring local business or local government vulnerability even though businesses and governments are also differentially affected natural hazards. Our goal is to create measures that are easily replicable using readily available data and that are easy to explain to local planners, policy makers, and citizens. We implement our measures of local business and government vulnerability for our study area, Coastal Virginia. We then combine those measures with a physical vulnerability measure to identify the areas in Coastal Virginia where planners and policy makers need to more closely examine the potential impacts of sea-level rise on their local businesses and government. While our methods are tailored to Coastal Virginia, they could be easily applied in other areas threatened by sea-level rise.

Keywords: Vulnerability, Sea-Level Rise, Local Government Exposure, Local Business Exposure

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1. Introduction

For well over three decades, scholars from a wide range of disciplines have been discussing and debating the consequences of sea-level rise (SLR) for coastal communities (Titus 1986; Yohe 1990; Nichols and Cazenave 2010; Neumann et al. 2012). Because coastal communities are complex, interdependent systems, SLR and the natural hazards that accompany it will have numerous, often cascading, impacts on the environment and on individuals within coastal communities, as well as on the local economy and government. Thus it is important to understand not only the potential physical impacts that SLR is likely to have, but also to understand its likely socio-economic impacts. While the literatures on physical and social vulnerabilities are generally quite well developed (Cutter et al. 2003; Tebaldi et al. 2012; Neumann et al. 2015; and Stafford and Abramowitz, 2017), there has been much less attention paid to understanding the vulnerability of local economies and governments to SLR. However, as local governments develop plans for adapting to SLR and recovering from the natural hazards associated with it, the ability to identify such vulnerabilities is crucial in putting together effective and efficient plans.

This paper focuses on creating methods for identifying the vulnerability of local businesses and governments to SLR so that local governments can better plan for it. We first examine the existing literatures on local business and government vulnerabilities to natural hazards in general. We then propose methods for measuring such vulnerabilities with respect to SLR and implement those methods for our study area, Coastal Virginia. We combine these measures of business and government vulnerabilities with a physical vulnerability measure to identify the areas in Coastal Virginia where planners and policy makers need to more closely examine the potential impacts of SLR on their businesses and local government.

2. Study Area

As shown in Figure 1, the Coastal Virginia area of the United States includes communities located on the Atlantic Ocean as well as communities located on the Chesapeake Bay and along the many tidal rivers in Virginia. This area includes a wide range of rural, suburban and urban communities. Over the past 80 years, the sea level in Coastal Virginia has risen more than one foot causing a loss of shoreline and increased flooding in many communities (VIMS, 2013). Global climate change threatens to magnify these problems as land in tidal flood zones becomes increasingly unusable hurricanes and other extreme weather events increase. Relative to most other U.S. locations facing SLR, Coastal Virginia is experiencing higher increases in net SLR due to a variety of factors, including significant land subsidence and the prevalence of low-lying flood-prone terrain. Since Coastal Virginia is home to almost 5 million people with significant investments in coastal real estate, the monetary impacts of SLR are expected to quite large. One recent estimate found that over 50,000 homes worth over $17 billion in property value sit on land less than five feet above the current high tide line in Coastal Virginia. These figures jump to 200,000 homes worth almost $55 billion when one considers land less than nine feet above high tide (Strauss et al. 2014).

Because of its physical exposure, Coastal Virginia has been the focus of other studies looking at vulnerabilities to SLR. While Stafford and Abramowitz (2017) focus exclusively on measuring social vulnerability to SLR and other natural hazards in Coastal Virginia, Kleinosky et al. (2007) examine the vulnerability of the Hampton Roads region of Coastal Virginia in terms of both physical exposure to SLR and storm-surge flooding and social vulnerability. However, neither paper considers local business or government vulnerability to SLR.

3. Local Businesses Vulnerability to Sea-Level Rise

It is clear that a community's businesses and its local economy are vulnerable to natural hazards such as hurricanes, tornados, and flooding, just as its individual citizens are. Businesses may suffer direct losses as a result of damaged buildings, equipment and inventory as well as indirect losses due to a decrease in demand from affected customers, reduced labor from affected employees, loss of energy or water from affected utilities, or the inability to accept or send shipments due to damaged transportation networks. Even if only a few businesses are disrupted, there are likely to be ripple effects throughout the local economy. To date most of the focus on the effect of natural hazards on businesses tends to be conducted at a fairly aggregate level, measuring changes in the macroeconomic health of areas that have been affected by a natural hazard. The more limited literature on local business and economic vulnerability to natural hazards generally falls into two main categories: papers that focus on a theoretical discussion of the features of businesses that are likely to make them less resilient to hazards (Zhang et al. 2009) and papers that estimate the short-term or long-run impact of a specific hazard such as Hurricane Katrina on local businesses (Lam et al. 2012).

The theoretical literature on business vulnerability to natural hazards identifies a number of different factors that can contribute to business vulnerability (Tierney 2007). There is general agreement that the most important factor is the physical location of the business as that determines the likelihood of direct physical damage, including loss of physical assets and inventories, from a natural hazard. A key factor in determining the extent to which a business will suffer non-physical or indirect impacts is the sector in which the business operates. Because a major source of indirect losses is a decrease in customer demand, sectors that depend on discretionary spending from local residents such as retail trade and restaurants are likely to suffer in the wake of a natural disaster as victims may leave the area and those who remain are likely to have less discretionary income. Of course, there are some sectors such as construction and home improvement retailers that may see an increase in local demand after a natural hazard as part of the rebuilding effort.

Some businesses are also naturally more dependent on local infrastructure than others. Businesses that rely on consistent access to local electricity, gas, water, sewer and telecommunications networks which are themselves vulnerable to natural hazards are more likely to face disruptions than businesses that are self-sufficient in these areas or do not need access to such services to function. Similarly, some business sectors are more dependent on transportation networks such as highways and waterways that could be affected by natural hazards.

In addition to the sector in which the business operates, one of the most often discussed factors that affects business vulnerability is the size of the business. Not only are small businesses more likely to depend on local customers, they often lack the capacity to shift their operations to unaffected locations and they may lack appropriate insurance coverage or capital to recover (Zhang et al. 2009). Moreover, they are more likely to have managers and owners that are dealing with losses at home (Webb et al. 2000). Other factors may be specific to the local economy, such as the nature of the local labor pool. Since many natural hazards can result in temporary and long-term population relocation, if the local labor market is tight prior to a hazard, any subsequent relocation may make it difficult for a business to replace missing workers. Similarly, if the local labor pool is dependent on local transportation to access their workplaces, significant disruptions in the transportation network may impact local business.

Empirical analyses also provide insight into the factors that affect business recovery. Webb et al. (2000) compiled data from five surveys taken after various natural hazards to determine the factors that most affected business disruption and recovery. While they find that the vast majority of businesses return to pre-hazard levels in the long-run, some of the consistent factors that are correlated with a lower chance of or slower recovery are size, poor financial condition prior to the hazard, and declining industry conditions. The authors also find that construction-related businesses tend to do very well following a natural hazard. Xiao and Drucker (2013) examine the impact of local economic diversity on local employment growth and income recovery after the 1993 U.S. Midwest floods. They find that flooded counties with higher levels of economic diversity had higher levels of employment gains and income recovery than counties with lower levels of economic diversity. While they cannot identify the exact mechanism by which economic diversity increase resilience, they do offer three possible explanations: a portfolio effect whereby the impacts of shocks in a particular sector have a smaller effect on the total since each sector is a small portion of the total economy; better ability to match employee skills to businesses; and the existence of cross-industry externalities that spur innovation and increase adaptability.

3.1 Existing Measures of Business Vulnerability

We have identified two other papers that develop measures of business vulnerability. The first, Khazai et al. (2013), conducts an assessment of industrial vulnerability in the German state of Baden-Wuettermberg. The authors first develop a sector-specific Industrial Vulnerability Index (IVI) for sixteen key industry sectors based on the capital, labor, infrastructure, and supply chain dependency of the sector using a relatively complex model that identifies the "directed relationships and influences" between different variables. For the different regions in Baden-Wuettermberg, the authors calculate a regional IVI which is essentially the weighted average of the sector-specific IVIs based on the relative share of each sector in the region.

Song et al. (2016) take a simpler approach to calculating a composite business vulnerability index (BVI) for Bay County, Florida. The authors focus on four "crucial factors" that underpin business vulnerability: business capital, labor force, critical suppliers, and physical exposure. They construct a census-block based BVI using 12 variables, each of which is normalized as the ratio of the variable's value for the census block relative to the average for Bay County. The BVI is then the weighted average of these twelve normalized variables: the number of small

businesses; the number of women-owned businesses; the number of small wholesale and retail businesses; the number of finance, insurance and real estate businesses; the number of business under seven years old; the number of single-establishment businesses; the number of employees working in their place of residence; the number of employees commuting by public transport; the number of lifeline businesses; the length of road networks; the street density; and the proportion of main arteries.

Our measure of business and local economic vulnerability to natural hazards in Virginia takes a different approach than the two discussed above. While we follow those two studies in using existing available statistical data, we attempt to better tailor our measure to the range of local economies in our study area that includes both highly urbanized counties and independent cities such as Hampton, Norfolk, and Virginia Beach as well as largely rural counties such as Gloucester and Northumberland.

3.2 Method for Identifying Local Business Vulnerability in Coastal Virginia

Because our ultimate goal is to help local policy makers plan for SLR, we focus on creating measures that are easy to use and explain to a wide range of audiences. Rather than calculating a single index value that combines a number of different factors together in one measure, we develop a set of indicator variables that can help identify localities where business and local economic vulnerability could be a concern. We use data that are publicly available so that localities can easily update the measures as new data becomes available. Since most of the publicly available data on businesses from the U.S. Census Bureau is collected at the county level, rather than at some finer delineation such as the census tract, our analysis is conducted at the county/independent city level for the 45 localities listed in Table 1.

In developing the indicators, we focused on characteristics identified in the literature that either impede or enhance local economic recovery following the types of natural hazards associated with SLR. We selected eight indicators that can easily be constructed from publicly available data: economic diversity, percentage of small businesses, presence of non-employer establishments, percentage of retail and wholesale trade, percentage of tourism businesses, percentage of leisure-oriented businesses, percentage of land-dependent businesses, and trends in economic conditions. For each of these indicators we established a threshold level above which one might have concerns about the vulnerability of local businesses and the economy. In establishing the threshold levels, we considered what the average level is across all of Virginia, rather than looking only at the average for Coastal Virginia. Admittedly these threshold values are somewhat arbitrary and we are not suggesting that crossing the threshold necessarily means that a particular locality will not recover from a natural hazard. Rather, a value above the threshold suggests that the locality could be vulnerable in that particular dimension and warrants a closer examination. The eight business indicators and their threshold values are described below.

B1: Economic Diversity. Since local economies that are more diverse tend to recover more robustly following a natural hazard, following Xiao and Drucker (2013) we create a measure which accounts for the range of industries in the local economy. Industries are defined at the 2-digit North American Industry Classification System (NAICS) level and we calculate the

percentage of total annual payroll that each industry represents. We then create a Herfindahl-Hirschman Index (HHI) of local economic diversity by squaring industry's percentage and then summing the squares across all industries.[1] The closer the index is to one, the more focused the economy is on a single sector. The data for this index were taken from the Census Bureau's 2015 County Business Pattern dataset. Across all Virginia localities, the average local economic diversity index value is 0.15 with a standard deviation of 0.07. Since higher values of the index indicate less diverse economies, we set our threshold for this variable at 0.25. An index value of 0.25 is consistent with one sector being responsible for almost half of the payroll in a particular locality. Only one locality in Coastal Virginia, King George county, has a local economic diversity index value above 0.25.

B2: Percentage of Small Businesses. Since many studies have shown that small businesses are less likely to recover following a natural hazard, we created an indicator based on the percentage of businesses in a locality that employ less than 20 individuals.[2] More specifically, we calculated the percentage of employees in a locality that work at establishments with less than 20 employees using data from the Census Bureau's 2011 Statistics of U.S. Businesses, State, MSA & County dataset. Across all Virginia localities, the average percentage of small business employment is just over 26% with a standard deviation of 11%. We set our threshold for this variable at 50%, which would indicate a local economy where over half of all employees work in small businesses. Three localities in Coastal Virginia have a small business percentage above this threshold.

B3: Presence of Nonemployer Establishments. The small business measure defined above only includes businesses with paid employees. There is also a category of businesses known as "nonemployer establishments" that we believe are similar to small businesses and are likely to face significant vulnerabilities to natural hazards. These are businesses that pay federal tax but do not have any paid employees, primarily individuals who work for themselves (watermen, carpenters, house-cleaners, consultants, etc.) and do not employ any other individuals. Not only do these businesses face the same hurdles that small businesses face when responding to natural hazards, it may be easy for such businesses to move out of an area following a natural hazard. We use the ratio of total revenues from nonemployer establishments in the locality to the total revenues from employer establishments. The numerator is taken from the Census Bureau's 2015 Nonemployer Statistics and the denominator comes from the Census Bureau's 2015 County Business Pattern dataset. Across all Virginia localities, the average ratio is just below 0.30 with a standard deviation of 0.23. We set our threshold for this variable at 0.75. At this level, non-employer business account for over 40% of total revenues in the local economy. Four localities in Coastal Virginia have a nonemployer establishment ratio above this threshold.

B4: Percentage of Trade. Retail and wholesale trade businesses are likely to suffer significantly from natural hazards for several reasons. First, both sectors are particularly dependent on

[1] Based on data availability, we use the 2-digit NAICS to define sectors. While Xiao and Drucker (2013) use 3-digit NAICS in their analysis, they found that the results were generally consistent when the 2-digit NAICS was used.
[2] The formal definition of a small business according to the Small Business Administration depends both on the number of employees and the particular sector. To make our variable easy to replicate, we elected to use 20 employees as our cutoff point, regardless of sector. Since there is a high correlation between measures that use 20, 100, and 500 employees as cutoff points, this measure is robust to other definitions of a small business.

transportation networks to deliver goods to and from the business. Additionally, retail trade is typically dependent on local customer or tourist demand. Therefore, the larger the trade sector in a local economy, the more vulnerable the economy. For this indicator, the percentage of the local economy that is engaged in trade is measured as the percent of total payroll that is paid to employees of businesses classified as in Wholesale or Retail Trade (i.e., in NAICS 42, 44, or 45) in the Census Bureau's 2015 County Business Pattern dataset. Across all Virginia localities, the average percentage of trade in the local economy is 15% with a standard deviation of 6%. We set our threshold for this variable at 25%, or one-quarter of the economy devoted to trade. Five localities in Coastal Virginia have a retail or wholesale trade percentage above this threshold.

B5: Percentage of Tourism Businesses. Another sector that is likely to experience significant decreases in customer demand after a natural hazard is the tourism sector. The percentage of the local economy that is engaged in tourism is measured as the percentage of total 2015 payroll paid to employees of tourist-related businesses as defined by the U.S. Travel Association.[3] Across all Virginia localities, the average tourism-related share of the economy is 6% with a standard deviation of 8%. We set our threshold for this variable at 25% or a quarter of the economy related to tourism businesses. Three localities in Coastal Virginia have a tourism percentage above that threshold.

B6: Percentage of Leisure-Oriented Businesses. In addition to expecting a decrease in tourism in an affected area, we also expect a decrease in the consumption of leisure activities (eating out, going to movies, etc.) by locals after a natural hazard. We measure the percentage of the local economy that is engaged in leisure-oriented business, defined as businesses in arts, entertainment, and recreation (NAICS 71) and accommodations and food services (NAICS 72). As is the case with other similar measures, we calculate this as the percentage of total payroll paid by employers in those sectors relative to the overall economy based on data from the Census Bureau's 2015 County Business Pattern dataset. Across all Virginia localities, the average percentage of leisure-oriented businesses is 6% with a standard deviation of 5%. We set our threshold for this variable at 10% and six localities in Coastal Virginia exceed this threshold.

B7: Percentage of Land-Dependent Businesses. Businesses that are directly dependent on land to produce their product, such as agriculture or fishing, are also likely to be vulnerable to natural hazards as are businesses engaged in the development and sale of real estate. For example, Xiao (2011) finds the farm employment and income were significantly lower in areas affected by the 1993 Midwest floods in both the short- and long-run. While the FIRE (finance, insurance, and real estate) service sectors are often seen as being relatively insulated from natural hazards, for natural hazards associated with SLR, such as increased recurrent flood and storm surge, we believe that real-estate is likely to be negatively impacted. This indicator measures the percentage of the total payroll paid by employers in land-dependent businesses, specifically agriculture, forestry, hunting and fishing (NAICS 11) and real estate (NAICS 53). Across all Virginia localities, the average percentage of land-dependent businesses is 2% with a standard deviation of 2%. We set our threshold for this variable at 5% and three localities are above that threshold.

[3] Tourist related payroll data is available the Virginia Tourism Corporation. We used data on total payroll from the 2015 County Business Pattern dataset from the Census Bureau.

B8: Trends in Economic Conditions. The literature also suggests that economies that are already experiencing economic decline are less likely to recover strongly compared to economies that are growing. We measure trends in economic conditions using the percentage change in annual payrolls from 2010 to 2015 from the Census Bureau's County Business Pattern dataset. Across all Virginia localities, the average change in annual payroll is a positive 15% with a standard deviation of 10%. We set our threshold for this variable at negative 10%, that is a 10% or greater decline in the total payroll for a local economy from 2010 to 2015. Only one locality in Coastal Virginia, experienced a l0% or greater decline between 2010 and 2015.

Table 2 shows the various localities in Coastal Virginia that exceed one or more of the Business Indicators. Note that 31 of the 45 localities in our study area do not cross any of the thresholds. The remaining 14 localities are vulnerable along a least one of the dimensions discussed above. For those localities that do cross one or more threshold, we recommend a more complete examination of the particular area in which the indicator raises concerns. Local governments that do find cause for concern can then work with their local businesses to develop short and long-term hazard management and mitigation plans to address those vulnerabilities.

4. Local Government Vulnerability to Sea-Level Rise

As is the case with local businesses, local governments may also experience direct and indirect impacts from natural hazards associated with SLR. A relatively invulnerable local government should be able to maintain adequate service levels soon after flooding or storm events and should be able to adjust to any long-term economic or demographic changes that result from such events or other consequences of SLR. Conversely, a vulnerable local government will struggle to provide adequate services after flooding or storm events and will have a difficult time adjusting to long-term changes in the community and economy. Much attention has been paid to making sure that local governments have the capacity to respond to natural disasters. In particular, there has been a significant effort focused on ensuring that local governments have engaged in adequate emergency planning and response activities for the types of natural disasters that they are likely to encounter. There has been less attention paid to ensuring that local governments are prepared fiscally to respond to natural hazards and adapt in the long run, which is the focus of our approach. While we recognize that vulnerabilities of business and the local economy is an important component of local government vulnerability, as they form a large part of the local government's tax base, to avoid double counting, this part of the exercise focuses on identifying additional dimensions of local government vulnerability that are not directly related to businesses.

While there is a large literature on how to evaluate the overall fiscal health of local governments (Honadle et al., 2004), we found very little theoretical literature on local government vulnerability to natural hazards.[4] A few publications discuss the primary pathways through which natural hazards can affect the local government finances. Fannin and Detre (2012) note that local governments cannot buy insurance for costly emergency expenses such emergency operations and shelters, additional police efforts and debris removal. Such out-of-pocket expenditures can create short-term financial problems for governments that are liquidity

[4] There is a theoretical literature on *national* government vulnerability to natural hazards. Benson and Clay (2004) provide an introduction.

constrained and, depending on the extent of the damage, may have a negative impact on the locality's long-term financial status. Although FEMA has covered 100 percent of the emergency and clean-up costs incurred by local governments in many past disasters, it can require up to a 25 percent cost share from local governments. Given the current federal budget and the number of significant disasters to which FEMA has provided assistance, there is increasing concern that FEMA will require local governments to shoulder a higher percentage of costs in the future. Similarly, while other federal agencies may contribute to the costs of emergency programs (e.g., an emergency food stamp program under the USDA), local governments are often expected to share in the operational costs associated with such programs.[5] Even if the federal and state governments do fully reimburse local governments for emergency and clean-up costs, in the short-run local governments will likely have to cover a significant level of expenses out of pocket and it will likely take significant time to receive reimbursements from various federal and state sources.[6] Finally, for events such as increased recurrent flooding from SLR that are not formally declared disasters, local governments are likely to have to cover a large percentage, if not all, of such costs.

In addition to the short-run budgetary impacts of paying for emergency and clean-up costs and additional health and welfare expenses, Johnson (2014) notes that local revenue sources such as property and sales taxes may be affected in both the short and long runs. On the positive side, a recent paper on the effect of natural disasters on state finances, Miao, Hou, and Abrigo (2016), finds that state sales tax revenues rise initially after a disaster rather than fall, presumably as citizens prepare for and respond to the disaster. Moreover, they find that in the long run there is no significant effect of natural disasters on state sales tax revenues. It is likely this finding will translate to local sales taxes as well, aside from those sales taxes that are particularly dependent on tourism. For tourism-based sales taxes, one would expect that at least in the short-run (and potentially in the longer run depending on the extent of the natural hazard), such taxes would decrease significantly, particularly since there is likely to be no offsetting shift in tourism dollars to other sites. For example, if a hurricane shifts tourist activity from the coast to the interior, the state may remain close to whole, but the coastal county will be negatively impacted.

Depending on the extent of the damage to property from flooding and SLR, local governments that are highly dependent on property taxes may also face budgetary issues over the longer term. While property taxes have long been recognized as a relatively recession-proof form of local government revenues, Miao, Hou, and Abrigo (2016) find that state property taxes decrease after a natural disaster. Similarly, after Hurricane Sandy, the Division of Local Government Services in New Jersey estimated that more than a dozen municipalities in the state could lose at least 10 percent of their tax bases (Cowan, 2013) and a recent analysis by the New York Times found that Ocean County N.J.'s tax base had declined by 8 percent (Corasaniti, 2017). Additionally, with SLR some property will become uninhabitable or undevelopable over time and property owners should have a pretty compelling case for decreasing their assessments, which will result

[5] To our knowledge, there has not been a formal analysis of the extent to which local governments incur unreimbursed expenses from natural disasters. However, a recent study of the effect of natural disasters on state finances by Miao, Hou, and Abrigo (2016) found that even though states receive significant amounts of transfers from multiple agencies of the federal government in response to a natural disaster, the increases in public spending on health and welfare in a state is larger than the federal transfers, resulting in a net negative effect on state finances.
[6] According to Fannin and Detre (2012) it typically takes between three months and two years for FEMA to reimburse local governments.

in a decrease in property tax revenues unless local tax rates increase. Given the often relatively high values of waterfront property, significant reductions in their assessments could have a disproportionate impact on coastal locality income.

4.1 Existing Measures of Government Vulnerability

There are only a few papers that attempt to measure or identify local government vulnerability to natural hazards. Fannin and Detre (2012) suggest using two financial ratios – the Current Ratio and the Debt to Net Asset Ratio – relative to expected short-term response, cleanup, and removal costs to assess fiscal vulnerability. However, to apply this measure one must also have an estimate of the expected short-term costs. In areas that have recently experienced natural hazards such as the Louisiana and Mississippi counties the authors study, such estimates can be developed from past experiences, but in other locations, such estimates may be difficult to create. An alternative method for estimating local government vulnerability is presented in Fannin and Miller (2013). This method requires individuals with detailed local knowledge such as local planners or fiscal managers to estimate the locality's financial vulnerability to hazards as well as its financial capacity through a series of worksheets. However, like the Fannin and Detre (2012) approach, the focus is on short-term costs such as emergency services and clean-up and removal.

4.2 Method for Identifying Local Government Vulnerability in Coastal Virginia

Following our approach with the business vulnerability measure, we created a second set of indicator variables using readily available data to identify local governments where fiscal vulnerability is a potential concern. We focus on three different dimensions of vulnerability: is the local government well positioned to absorb the expenses associated with responding to and recovering from flooding and storm events, will the locality's budget be significantly impacted by such events in the short run and/or the long run, and does the locality itself have significant assets that are at risk from SLR. The majority of the data used to create these measures is taken from each localities' 2015 Comprehensive Annual Financial Report (CAFR) and the analysis is conducted at the county/independent city level.

We created five indicator variables for local government exposure to natural hazards: two are proxies for the local government's ability to absorb the short-term emergency response and clean-up expenses, two are proxies for the locality's ability to weather short-run and long-run impacts from the disaster, and one is a proxy for the potential exposure of government assets to a natural disaster. For each of these indicators we established a threshold level above which one might have concerns about the vulnerability of local government. As was the case with the business indicators, in establishing the threshold levels we considered what the average level is across all of Virginia and we acknowledge that the choice of threshold values is arbitrary, although they are based on the distribution of values across counties. The five government indicator variables and their thresholds are described in more detail below.

G1: Net Position per Capita. A government's net position is a measure of its overall fiscal health and is equal to its net investment in capital assets, net restricted assets, and net unrestricted assets. Since local governments in Virginia vary quite significantly in the size of their population, we measure net position on a per capita level. The higher the net position per capita,

the better the long term fiscal health of the local government. In particular, when facing a natural disaster, healthy governments will be better able to finance emergency, clean-up, and other costs whether by using cash assets or by taking on additional debt. Across all Virginia localities, the average net position per capita is just over $2,200 with a standard deviation of just over $2000. We set our threshold for this variable at $500 per capita, or about a quarter of the state average net position per capita. Three localities have a per capita net position below that threshold.

G2: Percent of Expenses Spent on Health and Welfare. Health and welfare expenses are likely to increase after a natural disaster as citizens experience loss of income, loss of property, and perhaps an increase in disability or illnesses. Local governments that have a population with higher needs are likely to see the largest increases in such expenditures. We use the percentage of local government expenses that are directed toward health and welfare as a proxy for the needs of a local government's population and anticipate that those governments that currently spend a significant proportion of their budget on health and welfare could be in a difficult position if such expenses were to rise significantly after a natural disaster.[7] Across all Virginia localities, the average percentage of expenditures spent on Health and Welfare is 10% with a standard deviation of almost 6%. We set our threshold for this variable at 15% and only one Coastal Virginia locality spends in excess of 15% of their expenditures on health and welfare.

G3: Percent of Revenues from Tourism. Tourism is expected to decline, at least in the short run, after natural disasters. Governments that are particularly dependent on tourism for revenues are likely to see a negative impact on their budgets following a disaster. We use data on local lodging, food, and amusement excise taxes from the Virginia Tourism Corporation's Virginia Locality Economic Impact Data and data on general government revenues to generate this measure.[8] Across all Virginia localities, the average percentage of general revenues that come from tourism is 5% with a standard deviation of 6%. We set our threshold for this variable at 15% percent. Two localities receive in excess of 15% of their general revenues from tourism.

G4: Percent of Revenues from Property Tax. In the long-run, governments that are heavily dependent on property tax revenues may see their tax base erode if property is sufficiently damaged by natural disasters or devalued by SLR. We calculate the percent of general government revenues that come from local property taxes for this indicator. Across all Virginia localities, the average percentage of general revenues that comes from property taxes is 68% with a standard deviation of about 13%. We set our threshold for this variable at 80% percent. Five Coastal Virginia counties receive in excess of 80% of their general revenues from property taxes.

G5: Net Position to Capital Assets. This indicator is the ratio of the government's net position, including component units, to the capital assets owned by the government and its component

[7] An alternative measure would be per capita expenses on health and welfare. However, we are concerned that localities with more generous services across the board might have high per capita expenses in this area even if their population is not particularly needy.

[8] Local general revenue does not include revenue that is earmarked for particular programs. However, total revenue and general revenue are highly correlated so we would get similar results if we used total revenue as our normalizing factor.

units.[9] We compare the net position to capital assets because governments that have a low net position relative to their capital assets are not in a position to replace those assets were they to be damaged. This ratio will be particularly low for those governments that carry a lot of debt but also hold a lot of capital assets. The ratio will be high for governments that have significant net assets – both capital or financial – relative to their debt levels as well as for those governments who do not own significant capital assets. We include this measure because local governments may themselves own assets that could be damaged or destroyed by a natural hazard. While many of these assets will be insured, they may not all be. Even with insurance there will be unreimbursed costs to the government. Across all Virginia localities, the average ratio of net position to capital assets is almost 0.4 with a standard deviation of 0.35 – that is the net position is approximately 40% of the value of capital assets on average. For this variable, the threshold is set at 0.05 and localities with lower values are assumed to be vulnerable. The two Coastal Virginia localities that are below this threshold, Isle of Wight and Richmond County, both have a negative net position.

As we did with the business indicators, we classify each local government based on whether the values for each indicator variable cross the specified threshold as shown in Table 3. Only 11 localities appear to be vulnerable to SLR with respect to their fiscal position. For those local governments that do cross one or more threshold, we recommend a more complete examination of the local government's fiscal position to determine the exact nature of the local government's vulnerability and to identify a path for limiting the vulnerability and building the government's resilience to natural hazards.

5. Identifying Physical Vulnerability to Sea-Level Rise

Much of the literature on identifying various vulnerabilities to natural hazards combines various dimensions of social vulnerability with some measure of physical vulnerability for a given location, consistent with Cutter's (1996) hazards-of-place model. In this paper, we follow this framework, independently identifying the physical vulnerability of localities before combining with the business and government vulnerabilities identified above.

Scholars have taken a wide range of approaches to identifying physical vulnerability to SLR. Some take available and well-established data on flood risk zones while others develop their own complex models for a range of different SLR scenarios.[10] For this paper, we use a measure of physical vulnerability developed explicitly for Coastal Virginia by the Center for Coastal Resources Management (CCRM) at the Virginia Institute of Marine Science (VIMS) (Stafford and Renaud 2017). This index provides a broad perspective on the vulnerability of Coastal Virginia, creating a composite measure of vulnerability to coastal flood and SLR impacts rather than the threat of any one particular storm track. The index captures multiple factors that affect exposure to SLR: elevation, coastal slope, developed land, wave exposure, and tide range. This

[9] Capital assets are net of accumulated depreciation, but not net of the debt owed on those assets. The capital assets include land and land improvements, buildings, machinery and equipment, and infrastructure construction. For this measure we include both the government and its component units (legally separate organizations for which the elected officials of the primary government are financially accountable such school districts, public utilities and housing authorities).

[10] While it is beyond the scope of this paper to provide a review of the various methods for estimating the impacts of SLR, Slangen et al. (2017) provide a review of the recent papers estimating SLR at global and regional scales.

index is not intended to replace the use of higher-resolution hydrodynamic risk models for specific locations, but like our other measures of vulnerability, we believe this index is both actionable and easy to communicate to local policymakers.

The CCRM physical index is measured at the census tract level and consists of five components: the percent of the census tract that has an elevation that is 10 ft. (3.05 m) or less above sea level, the volume of land between sea level and 10 ft. above sea level relative to the area of land between these two thresholds, the percentage of land below 10 ft. above sea level that is developed, the average wave energy along the tract's shoreline, and the average tidal range along the tracts shoreline. Each of these variables is standardized so that the minimum value is zero and the maximum value is 1 with 1 indicating the highest level of vulnerability. The index is an equal-weighted average of these five variables with the highest possible value equal to 1 and the lowest equal to 0.

The county-level physical vulnerability index (PVI) measure that we use in this paper is a weighted average of the census tract-level index where the weights are the land area in each census tract. Across the 45 Coastal Virginia localities, the average PVI is 0.3 and the standard deviation is 0.2 with a maximum of 0.83. Rather than creating a unique threshold, we identified three tiers of localities based on their PVI. As shown in Table 4, in the "highest" tier are the nine localities whose PVI exceed 0.5. In the "very high" tier are seven additional localities whose PVI falls between 0.4 and 0.5 and in the moderately high tier are 8 more localities whose PVI falls between 0.3 and 0.4. Since this information provides only a rough sense of the potential for a county to experience physical consequences from SLR, for local governments that have relatively high PVI, we recommend a more complete examination of the local government's physical vulnerability using the Adapt Virginia Web Portal (www.adaptva.org), which provides a wide range of tools to help local planners and policy makers understand the threats from SLR, storm surge and flooding.

6. Analysis of the Combined Local Business and Government Vulnerability to Sea-Level Rise

To fully understand local business and government vulnerability to SLR, we combine the physical vulnerability index with the business and government vulnerability indicators. Table 5 identifies those localities that have high physical vulnerability and exceed one or more of the business or government indicator thresholds. Three of the localities with the highest level of physical vulnerability also have vulnerable local economies or governments. Matthews County, which borders the Chesapeake Bay has a physical index of 0.54 and an economy with a very high percentage of small business and nonemployer establishments, as well as a high percentage of trade and tourism oriented businesses. In the event of a significant storm event, the area could see a significant decline in its economy. Northampton County, which lies between the Chesapeake Bay and the Atlantic Ocean has a physical index of 0.52 and a high percentage of both leisure-oriented and land-dependent businesses which are also likely to suffer significantly both from storm surge and from the more gradual impacts of SLR. The final locality in the highest physical vulnerability category is Poquoson, an independent city bordering on the Chesapeake Bay, with a physical index of 0.83 and a high percentage of nonemployer businesses which are at risk of relocating after a significant storm event.

There are five localities in the "very high" tier for physical vulnerability that also face some types of business and government vulnerability, many of which are shared. Both Middlesex and Northumberland have a high percentage of small businesses while King and Queen and Northumberland have a high percentage of nonemployer establishments. Middlesex and York have a high percentage of leisure-oriented businesses while King and Queen and Northumberland both have a large percentage land-dependent businesses. Finally, both King William and Northmberland have governments who collect a high percentage of revenue from property tax. However, each locality's combination of potential vulnerabilities is unique, emphasizing the need for each locality to use these indicators as a first step in a more in-depth analysis of the likely consequences of SLR, storms, and flood events on their economies and governments.

The localities with a moderately high level of physical vulnerability include a number of locations along Virginia's tidal rivers as well as Gloucester County on the Chesapeake Bay. Similar to the localities with higher levels of physical vulnerability, some of the key concerns for these localities are high levels of retail trade, a high percentage of leisure-oriented businesses, and a high percentage of tax revenues coming from property taxes. Colonial Heights also has a high percentage of tax revenues coming from tourism, which would likely be impacted by both SLR and specific storm and flooding events. Interestingly, neither King George County or Richmond County exhibit vulnerability along those dimensions, although King George exhibits a lack of economic diversity which could slow recovery after any significant storm or flooding event and Richmond County has a low net position to capital assets ratio which would make it difficult for the government to recover from significant damages to its own assets from SLR and storm and flooding events.

7. Concluding Remarks

In this paper we present methods for identifying potential local business and government vulnerabilities to sea-level rise. These measures are designed to be easily replicable using readily available data as well as easy to explain to local planners, policy makers, and citizens. Our goal in creating these measures was to assist local governments in developing response plans to natural hazards arising from SLR and in coming up with ways to increase their communities' resilience. For our case study we combine these measures with a physical vulnerability index to identify particular localities in Coastal Virginia whose local businesses or government appear to be vulnerable to SLR in some way. Our approach is designed to alert local policy makers to these potential areas of vulnerability. Once particular areas are identified, we recommend a more complete examination of that area to better understand the extent of the vulnerability for the community. Policy makers can then work with their local businesses or government to develop short and long-term hazard management and mitigation plans to address those vulnerabilities.

While we conduct our case study for the Coastal Virginia area, we note that these methods can be applied more broadly to other areas that are threatened by SLR. The local business indicators presented here can be generated for other locations in the U.S. using readily available data from the Census Bureau. While requirements for counties in the U.S. to file annual financial reports vary across states, a majority of states do require counties to file the same CAFRs that were used

to calculate the government indicators recommended in this paper. Even if a county does not file a CAFR, most U.S. states require some form of annual financial reporting from counties. Outside of the U.S., the business indicators described here might have to be adjusted based on available data. However, the general approach should still hold, at least for similarly industrialized countries. The government indicators may be less transferrable, depending on the way in which local governments are financed. However, the rationale underlying our choice of government indicators can be used to develop alternate indicators. We also acknowledge that we may have left out some important dimensions of both local business and government vulnerability. Our intention with this paper was to spark additional discussion among academics and practitioners about the best ways to identify and quantity such vulnerabilities to SLR and other natural hazards.

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Figure 1: Coastal Virginia

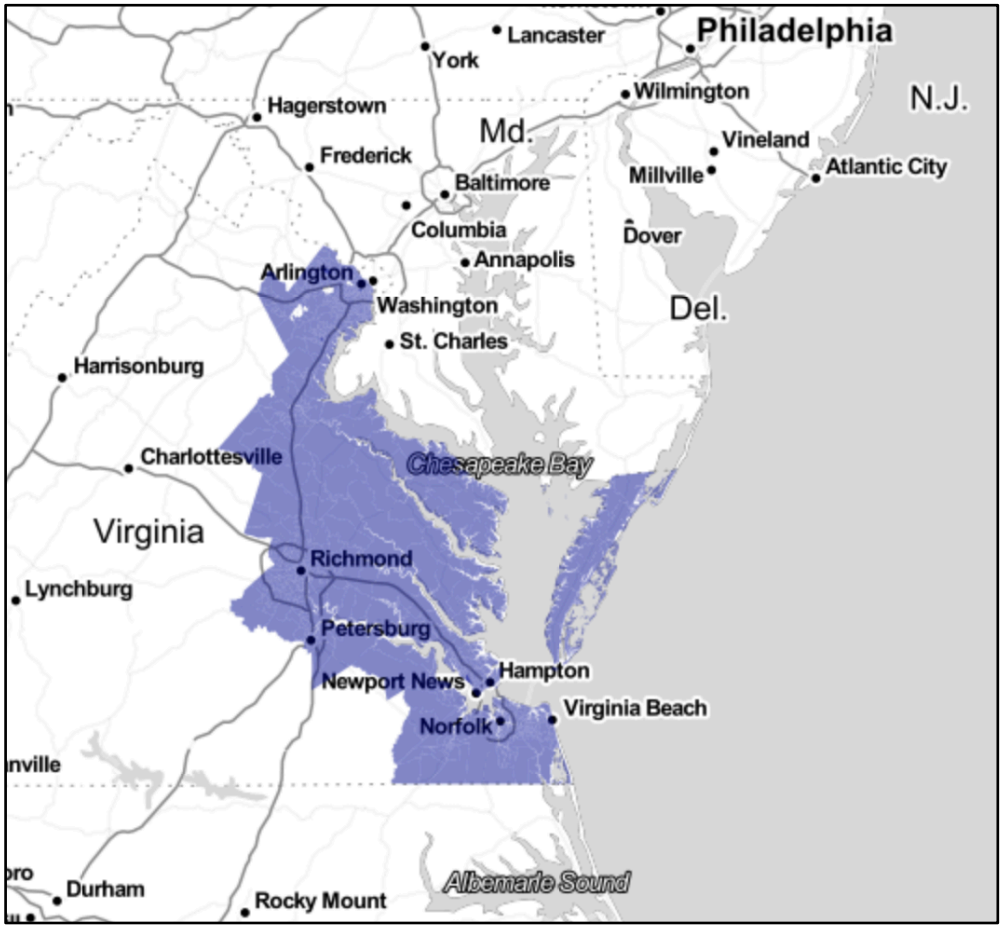

Figure 2: Physical Vulnerability of Coastal Virginia

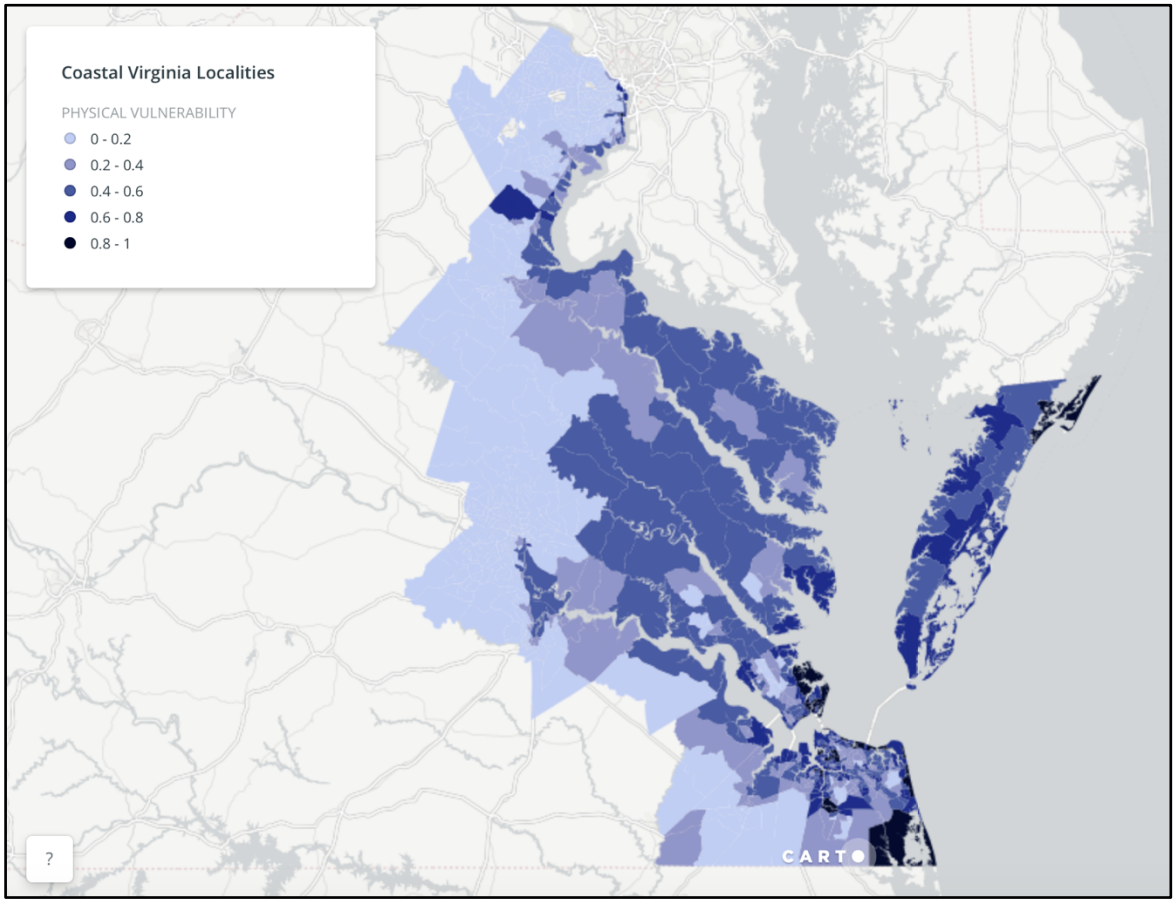

Table 1: Coastal Virginia Localities

Accomack	Henrico	Petersburg
Alexandria	Hopewell	Poquoson
Arlington	Isle of Wight	Portsmouth
Caroline	James City	Prince George
Charles City	King and Queen	Prince William
Chesapeake	King George	Richmond (City)
Chesterfield	King William	Richmond (County)
Colonial Heights	Lancaster	Spotsylvania
Essex	Mathews	Stafford
Fairfax (City)	Middlesex	Suffolk
Fairfax (County)	New Kent	Surry
Fredricksburg	Newport News	Virginia Beach
Gloucester	Norfolk	Westmoreland
Hampton	Northampton	Williamsburg
Hanover	Northumberland	York

Table 2: Localities that Cross Local Business Vulnerability Thresholds

Localities	B1: Lack of Economic Diversity	B2: High Percentage of Small Businesses	B3: Significant Presence of Nonemployer Establishments	B4: High Percentage of Trade	B5: High Percentage of Tourism Businesses	B6: High Percentage of Leisure Oriented Businesses	B7: High Percentage of Land-Dependent Businesses	B8: Declining Economic Conditions
King George	X							
Mathews		X	X	X	X			
Northumberland		X	X				X	
Middlesex		X			X	X		
King and Queen			X				X	X
Poquoson			X					
Colonial Heights				X		X		
Gloucester, Hanover, Prince George				X				
Williamsburg					X	X		
Northampton						X	X	
James City, York						X		

Table 3: Localities that Cross Local Government Exposure Thresholds

Localities	G1: Low Net Position per Capita	G2: High Pct. Exp. Health and Welfare	G3: High Pct. Rev. from Tourism	G4: High Pct. Rev. from Property Tax	G5: Low Net Position to Capital Asset Ratio
Isle of Wight	X			X	X
Fairfax (County), Prince William	X				
King and Queen		X			
Colonial Heights, Williamsburg			X		
Charles City, King William, Northumberland, Surry				X	
Richmond (County)					X

Table 4: Localities that with the Highest Physical Vulnerability

Physical Vulnerability	Localities
Highest: >0.5	Accomack, Hampton, Matthews, New Kent, Norfolk, Northampton, Poquoson, Portsmouth, Virginia Beach
Very High: 0.4 – 0.5	King and Queen, King William, Lancaster, Middlesex, Northumberland, Westmoreland, York
Moderately High: 0.3 – 0.4	Charles City, Colonial Heights, Essex, Gloucester, James City, King George, Newport News, Richmond (County)

Table 5: Localities with Combined Vulnerabilities

Physical Vulnerability	Localities (Thresholds Exceeded)
Highest: >0.5	Matthews (B2, B3, B4, B5), Northampton (B6, B7), Poquoson (B3)
Very High: 0.4 – 0.5	King and Queen (B3, B7, B8, G2), King William (G4), Middlesex (B2, B5, B6), Northumberland (B2, B3, B7, G4), York (B6)
Moderately High: 0.3 – 0.4	Charles City (G4), Colonial Heights (B4, B6, G3), Gloucester (B4), James City (B6), King George (B1), Richmond County (G5)