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Does resilience yield dividends? Co-benefits of investing in increased resilience in Cedar Rapids

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Abstract

Cedar Rapids, IA, offers a unique case study in planning for increased resilience. In 2008, Cedar Rapids experienced severe flooding. Rather than simply rebuilding, the city of Cedar Rapids began to invest in a resilient flood control system and in the revitalization of its Downtown neighborhood. This paper develops a Computable General Equilibrium (CGE) model for the regional economy of Cedar Rapids to quantify 'resilience dividends': net co-benefits of investing in increased resilience. A resilience dividend includes benefits to the community even if another disaster does not occur. We build a CGE model of Cedar Rapids at two different time periods: one in 2007, before the flooding, and one in 2015, after the flooding and initial investment in resilience. We show that a positive economic shock to the economy results in larger co-benefits for key economic indicators in 2015 than in 2007. Our approach illustrates how co-benefits are distributed throughout the economy.

Keywords

Co-benefits; resilience; natural disasters; CGE; C68; Q54; R11; R12

1. Introduction

Communities of all sizes face some form of natural hazard risk (Alexander, 2017). Resilience is the ability to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions (NIST, 2016b). Investing in increased resilience helps communities mitigate natural hazard risk, with the ultimate objective that a natural hazard does not become a natural disaster. However, high costs and long-term planning horizons often deter communities from undertaking such investments, especially when the return on investment may not be realized in the near term, if at all.

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A natural question is whether such investments can produce ‘co-benefits’: benefits for community objectives other than reducing natural hazard risk, such as increasing household income or reducing unemployment. The resilience dividend encompasses a broader set of potential benefits that can alter how decision makers view return on investment (Rodin, 2014). Fung and Helgeson (2017) define the resilience dividend as the net co-benefits from investing in increased resilience *in the absence of a natural disaster*. A positive resilience dividend can help decision makers make a ‘business case’ for resilience. Accounting for co-benefits of resilience planning allows long-term investments to be weighed against day-to-day benefits to the local economy.

Cedar Rapids, IA, a mid-size city in the Midwestern United States, offers a unique case study in planning for increased resilience. In 2008, Cedar Rapids experienced severe flooding. Rather than simply rebuilding, the city of Cedar Rapids began to invest in both flood mitigation and in the revitalization of its neighborhoods. In addition to investments into a resilient flood control system – a 20-year project that includes levees, removable walls, and new pump stations – the city of Cedar Rapids has also invested in the revitalization its Downtown in order to have a more dynamic local economy that can absorb shocks, such as extreme flooding, more easily (Helgeson et al., 2017a). In addition to making Cedar Rapids more resilient to natural disasters, revitalization of its neighborhoods, especially Downtown, also provides benefits for the local economy and social systems in the absence of a natural disaster. Such investments in the aftermath of a disaster are rare relative to simply rebuilding, making Cedar Rapids an attractive case study for quantifying co-benefits.

This paper presents a Computable General Equilibrium (CGE) model approach to estimating the resilience dividend that can be used to both quantify co-benefits at a high level, as well as to illustrate how co-benefits are distributed throughout an economy. To quantify the resilience dividend from investing in increased resilience, we build two CGE models of Cedar Rapids, each at different time periods: one in 2007, before the flooding, and one in 2015, after the flooding and initial investment in resilience. We first quantify avoided losses by simulating a flood event that only impacts the 2007 model. We then consider exogenous positive shocks (in particular, population growth, export demand, and productivity shocks), which occur in the absence of a natural disaster. After simulating the shock in each time period, we find increases in output, employment, and household income are larger in 2015 (‘post-resilience Cedar Rapids’) than in 2007 (‘pre-resilience Cedar Rapids’). The additional co-benefits in 2015, which are obtained in the absence of a disaster, comprise the resilience dividend. Moreover, the results demonstrate how co-benefits are distributed across sectors and across households.

The paper is organized as follows. Section 2 provides background on the resilience dividend and Section 3 on our case study, Cedar Rapids. Section 4 provides an overview of CGE modeling and its application to quantifying the resilience dividend discusses the data we use to build our CGE models. Section 5 presents the CGE models of Cedar Rapids and Section 6 presents the resilience dividends that result from each simulation. Finally, we discuss caveats and future directions in Section 7.

2. Background on the resilience dividend

2.1. Making a 'business case' for resilience

Rodin (2014) introduces the concept of the resilience dividend and presents examples from the real world to illustrate the idea and its value. The main idea behind the resilience dividend is that investing in increased resilience provides *co-benefits* that are often unaccounted for, such as social cohesion, job opportunities, environmental protections, and space for public use. The resilience dividend is an organizing principle meant to account for these added benefits of resilience planning.

Accounting for such co-benefits can assist communities in making a business case for resilience planning. For example, zoning changes for earthquake risk mitigation can have co-benefits for sustainability (Saunders & Becker, 2015); green infrastructure can mitigate the impacts of heavy rainfall while providing recreation amenities (Tomczyk et al., 2016); and beach promenades can protect communities at risk of tsunami while improving tourism (Khew et al., 2015). Resilience actions that could alleviate vulnerability to large-scale disruptive events may be seen as bad investments when ignoring co-benefits, due to the low probability, or absence entirely, of an event in a given time frame. Co-benefits can therefore be pivotal in the identification of the most effective and efficient resilience plan, but only if the *value* of such co-benefits is included in the assessment of a resilience plan.

On the other hand, economic valuation techniques, such as benefit–cost analysis (BCA) and life-cycle analysis (LCA), seldom capture the full range of benefits, costs, and losses associated with resilience planning. In particular, these methods are not designed to capture co-benefits of investing in increased resilience (Fung & Helgeson, 2017), in large part because accounting for co-benefits is not standard practice. However, methods like BCA can be extended, as in NIST (2016a) and Helgeson et al. (2017b), to include the value of co-benefits when evaluating the net-present value (NPV) of a resilience plan.

In a review of the literature, Fung and Helgeson (2017) find that the quantification of co-benefits is quite limited to date, constraining the ability to include co-benefits in the economic valuation of a resilience plan. Moreover, they find that much of the research on co-benefits focuses on climate change mitigation and adaptation. In cases where co-benefits of resilience planning are considered, it is within the context of a developing country. The main objective of this paper is to provide a way to quantify co-benefits, as an input to economic valuation of resilience planning.

2.2. Operationalizing the resilience dividend

A series of World Bank reports builds on Rodin (2014)'s idea and presents the 'Triple Dividend of Resilience', intended to capture the direct and indirect benefits of Disaster Risk Management (DRM) within the context of developing countries (Mechler et al., 2016; Tanner et al., 2015; Vorhies & Wilkinson, 2016). As in much of the literature on co-benefits of climate change mitigation, the focus is on identifying rather than quantifying co-benefits. The three dividends are identified as: (1) avoided or reduced losses, in the event of a disruptive event; (2) economic co-benefits from reducing disaster risk; and (3) additional co-benefits in addition to avoided losses and economic development. In the context of Cedar

Rapids, a mid-size city in a developed country, the second and third dividends are indistinguishable for the investments undertaken as of 2015, with neighborhood revitalization being the major component.

More recently, Bond et al. (2017) introduce the Resilience Dividend Valuation Model (RDVM) and present six case studies in the developing country context to illustrate. Note that Bond et al. (2017) define the resilience dividend as 'the difference in net benefits from a project developed with a resilience lens versus one that is not'. Thus the RVDM approach compares the return-on-investment (ROI) for a fixed dollar amount spent on a resilient investment to the ROI for the same dollar amount spent on a non-resilient investment. In essence, the RVDM does two things simultaneously: quantifying co-benefits of investing in increased resilience and economic valuation of the resilience plan itself.

In the context of Cedar Rapids, the RVDM approach would require comparing a post-resilience Cedar Rapids to a Cedar Rapids that invested the same amount of money on a project that does not contribute to increasing resilience. In this scenario, it is difficult to disentangle the value of the resilience plan as determined by the RVDM from the value of the co-benefits that contribute to its value, since a non-resilient investment may nevertheless contribute to a community's secondary objectives (in fact, a secondary objective of the resilient investment may be the primary objective of the non-resilient investment).

In contrast, the CGE approach in this paper compares the impacts of a fixed economic shock on post-resilience Cedar Rapids relative to post-resilience Cedar Rapids. As a result, our approach differs from Bond et al. (2017)'s RVDM in one important way: our sole focus is on quantifying co-benefits of resilience planning. Our results can be used as inputs to economic valuation of a resilience plan. Economic valuation is thus a separate step and beyond the scope of this paper (see Helgeson et al., 2017b for an implementation of this approach).

It follows that the resilience dividend in this paper is not the ROI from a resilient investment relative to a non-resilient investment. Instead, we define the resilience dividend as the *net* co-benefits to secondary objectives, such as employment and income growth, in the absence of a natural disaster. In this setting, net means the differential impact to post-resilience Cedar Rapids relative to pre-resilience Cedar Rapids from the same, non-disaster shock. The differential impacts indicate which of the two economies is best positioned to gain from a boost in productivity and by how much. Indeed, because we quantify net co-benefits across a range of macroeconomic outcomes, we obtain a range of resilience dividends. Importantly, this approach can quantify how resilience dividends are distributed across an economy, as discussed in Section 4.

3. Flooding and resilience in Cedar Rapids

3.1. The midwest floods of June 2008

The United States midwest experienced severe riverine flooding in June 2008, causing devastation across 9 states – Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin – and resulting in 24 fatalities and over 140 injuries, as well as significant loss of corn and soybean crops (Dirmeyer & Kinter, 2009). The extensive flooding resulted from a combination of heavy rainfall atop soils overly saturated from heavy winter snowfall and an unusually wet spring (FEMA, 2009b). Figure 1, which illustrates the extent of rainfall over the first half of June 2008, shows that several of these states, including Iowa, experienced 12 inches or more of rainfall over this 15-day period.

The flooding in Iowa was particularly severe, with rivers breaching levees in Cedar Rapids, Des Moines, and Iowa City. Rivers across Iowa crested at levels that resulted in flooding beyond the 100-year floodplain, resulting in over 1.2 million acres of corn and soybean crops lost with an estimated value of over $3 billion (FEMA, 2009b). In Cedar Rapids, flooding from the Cedar River exceeded even the 500-year floodplain (Tate et al., 2016). In retrospect, the 2008 Midwest Floods have been characterized by the US Geological Survey as a 500-year flood event, similar to the Midwest Floods of 1993 (Dirmeyer & Kinter, 2009).

A presidential disaster declaration for tornadoes and severe storms in Iowa, initially issued on 27 May 2008 for 4 counties, was amended after the June floods to include 85 of Iowa's 99 counties, as shown in Figure 2. A total of $1.25 billion in combined state and federal funds were approved to assist recovery from this disaster (FEMA, 2009a).[1]

3.2. Impact on Cedar Rapids

The Cedar River in Cedar Rapids, which runs roughly from the northwest of the city to its southeast, crested at 31.12 feet on 12 June 2008, a level that was over 11 feet higher than the previous record of 19.66 feet set in March 1961 (Holmes et al., 2008). This record-level flooding was 20 feet above flood stage, exceeding the 500-year floodplain area (FEMA, 2009b).

The city closed all bridges and evacuated the downtown area, resulting in zero flood-related fatalities. Nevertheless, the city experienced a total of $5.4 billion in damages and economic losses (FEMA, 2009b). The flooding affected an estimated 10 square miles (or 14% of the city), including 1,126 city blocks, nearly 5,400 homes, over 800 commercial and government buildings, and displaced an estimated 18,000 people (City of Cedar Rapids, 2019a). The areas near the river experienced the worst impacts, including the downtown area on the east side of the river, home to several government buildings (such as City Hall, which is actually located within the river on May's Island, as shown in Figure 3), and a largely residential area along the west side of the river. Since many of the affected homes affected were considered affordable, the flood had a disproportionate impact on disadvantaged households (Tate et al., 2016).

3.3. Investing in resilience in Cedar Rapids

In the aftermath of the 2008 flood, the city of Cedar Rapids responded by engaging the community over a 10-month planning process to develop a framework to not only recover from the flood, but to become resilient to future flooding (City of Cedar Rapids, 2019b). Beginning with a series of public open houses immediately following the flood, the city

[1]Federal assistance included roughly $265 million from approved Small Business Administration (SBA) loans, $122 million fromFederal EmergencyManagement Agency (FEMA) Individual Assistance Housing grants, and $590 million fromFEMA's Public Assistance program (FEMA, 2009a).

engaged the participation of over 1,200 residents in a Neighborhood Planning Process (NPP), incorporated input from the US Army Corps of Engineers (including a 5-year feasibility study), and developed its own studies on the social and economic impacts from not investing in flood protection.

The outcome of the initial public outreach was the *Framework for Reinvestment and Revitalization* (‘the Framework’), outlining a vision for Cedar Rapids as a “vibrant urban hometown – a beacon for people and businesses invested in building a greater community for the next generation” (City of Cedar Rapids, 2019b). At the core of the Framework is an extensive Flood Control System, envisioned to protect a stretch of 7.5 miles along the Cedar River. While the Corps study emphasized protecting the east side of the river, the city concluded from its own studies and from community feedback that it was important for any investment in flood resilience to protect both sides of the river. The Flood Control System Master Plan was formally adopted on 23 June 2015 and construction began in 2016 (City of Cedar Rapids, 2020a).

Importantly, the Framework emphasized ‘the creation of Sustainable Neighborhoods’, a concept that was subsequently fleshed out during the course of the NPP. The outcome of the NPP, the Neighborhood Reinvestment Plan, was approved by the City Council on 13 May 2009 (City of Cedar Rapids, 2019b). The Neighborhood Reinvestment Plan emphasized neighborhood revitalization as another key component in addition to the flood-control infrastructure. The revitalization focused on 10 neighborhoods, including Downtown, as well as the adjacent New Bohemia (NewBo) neighborhood and the historic Czech Village neighborhood across the river. Today, Czech Village, Downtown Cedar Rapids, and NewBo have become vibrant neighborhoods, attracting young professionals, entrepreneurs, and artists.

Figure 4 presents a map of the city of Cedar Rapids highlighting the three neighborhoods of Downtown Cedar Rapids, NewBo, and Czech Village, which have been particular targets for commercial and residential development to attract a younger, more dynamic work force. Due to their close proximity and size relative to the whole economy, the CGE model combines Downtown Cedar Rapids, NewBo, and Czech Village into a single spatial unit. For simplicity, the combined spatial unit is called ‘Downtown’.

The City of Cedar Rapids committed to raising $110 million on its own for the Flood Control System. As of 5 July 2018, the city had invested $10 million of its total commitment; the state of Iowa had provided $267 million; and $14 million had been provided by federal grants. In addition, the US Army Corps of Engineers awarded $17.4 billion for disaster recovery across the country, providing Cedar Rapids with $117 million (Morelli, 2018).[2] The city has also raised funds from private donors and other local groups.

[2] Authorization of the $117 million stipulated $41 million in local funding that the City could repay as a low interest, long term loan. On 16 February 2019, the City Council authorized payments of up to $86 million to the Corps, including potentially funding the $41 million up front rather than through the loan, as well as $45 million for elements of the flood control system beyond the approved scope (Morelli, 2019).

The Flood Control System was projected to take 20 years to complete. As of 2018, 10 years after the flood, the cost was estimated at $550 million (Morelli, 2018). The key components of the Flood Control System include levees, (permanent and removable) walls, gates, new pump stations, and raising bridges. While construction did not begin until 2016, by 2015 the city had already added a new amphitheater that doubles as a levee along the west side of the river and raised the city's water wells (City of Cedar Rapids, 2020b). The city had also completed the acquisition of 1,356 properties to protect land prone to flooding, largely on the west side of the river (Tate et al., 2016).

The investments Cedar Rapids undertook by 2015, as well as its commitment to a resilient flood-control system, should foster a safe environment for business, making Cedar Rapids more economically resilient. Moreover, such initiatives in the aftermath of a disaster are the exception rather than the rule in the United States. For these reasons, we chose Cedar Rapids as our case study to quantify co-benefits that accrue in the absence of a disaster.

It should be noted that 2008 ushered in another major catastrophe, one that affected the entire country. The Great Recession, which is officially recognized as beginning on December 2007 and ending on June 2009, saw large declines in gross domestic product (GDP), home prices, and stock markets, while unemployment rose to 10 percent by October 2009 (Rich, 2009). Such added downward pressure on the local economy makes the path Cedar Rapids took seem even more impressive. While it is impossible to disentangle the effects of the recession from the effects of the flood, the impacts of reinvestment are expected to move in the opposite direction. Thus they may be understated in the final CGE analysis.

4. Methodology: the CGE approach

A CGE model simulates the working of a market economy in which prices and quantities adjust to clear all markets. The economy is said to be in *equilibrium* when markets clear. Figure 5 illustrates the typical relationships in an economy modeled by CGE. Households maximize their welfare, firms maximize their profits, the government is assumed to have a balanced budget, and resources are limited and costly.

There is a growing literature that uses CGE analysis to estimate the impacts of natural disasters. Rose and Liao (2005) construct a CGE model for Portland, OR, to estimate sector-level losses from a hypothetical earthquake. Cutler et al. (2016) construct a spatial CGE model for an artificial city and demonstrate a method for linking engineering and economic models to describe earthquake damage and the subsequent economic losses. Dixon et al. (2017) present a wide range of CGE applications to natural disaster analysis. Kajitani and Tatano (2018) construct a spatial, nine-region CGE model to assess the impacts of the 2011 Great East Japan earthquake and tsunami. In Section 6.1, we use a spatial CGE model to estimate economic losses from flooding. However, our paper is unique in using two CGE models to estimate the benefits of investing in resilience *in the absence of a disaster*.

CGE analysis has also been used to study recovery from natural disasters. For instance, Xie et al. (2018) construct a dynamic CGE model to study mechanisms that could have accelerated recovery from the Wenchuan earthquake. Attary et al. (2020) use a CGE model for Joplin, MO, to estimate the economic costs of waiting for federal assistance. While our paper does not study recovery directly, we show that investing in recovery can provide non-disaster benefits for economic growth.

A special issue of this journal was devoted to modeling natural disasters using variants of input-output (IO) models. Kajitani and Tatano (2014) estimate the production capacity loss rate (PCLR) due to the Great East Japan earthquake, while Okuyama (2014) demonstrates the spatial heterogeneity of impacts from the Kobe earthquake. Santos et al. (2014) use a dynamic IO model to assess the propagation of natural disasters for Nashville, TN, with a focus on recovery. Yu et al. (2014), on the other hand, derive a vulnerability index based on economic impact, propagation length, and sector size that can be used to optimize investments following a natural disaster. Finally, Jonkeren and Giannopoulos (2014) focus on increased supply-chain inventories as a measure of resilience in a dynamic IO model of recovery. Our paper add to this literature by providing spatial estimates of the economic benefits of disaster mitigation policies.

4.1. CGE models to quantify resilience dividends

The objective of this paper is not to analyze the impacts of a natural disaster or a policy change such as investing in increased resilience. Rather, the goal is to quantify the net co-benefits that accrue from those investments *in the absence of a disaster*. Thus we use a counterfactual approach to compare the impacts of a positive economic shock that is orthogonal to natural hazard events on two different economies: Cedar Rapids in 2007, before the flooding and any investments in resilience (the ‘pre-resilience’ model), and the Cedar Rapids in 2015, after the flooding and some initial investments in resilience (the ‘post-resilience’ model). Each model represents a status quo (pre-shock) equilibrium. In other words, the two models are ‘snapshots’ of the 2007 and 2015 economies, respectively. The snapshots may be thought of as alternative states of the world, providing plausible counterfactuals for quantifying resilience dividends.

One of the biggest differences between the two economies is the investment neighborhood revitalization, in particular that Downtown.[3] We use comparative statics to quantify the impacts of the exogenous shock for each model and compare post-shock outcomes for post-resilience Cedar Rapids to those of pre-resilience Cedar Rapids. Differential impacts are largely attributed to the investments in increased resilience in the post-resilience model. These differences are the net co-benefits from investing in increased resilience; that is, the differences quantify the resilience dividends.

While the CGE approach provides a broad picture of how co-benefits are distributed throughout an economy, spatial CGE (SCGE) models allow for the exploration of the distributive effects of resilience planning, in particular, how resilience dividends are distributed spatially. Thus we use annual economic data to build the two SCGE models of Cedar Rapids. Each model is spatial in the sense that we distinguish impacts to Downtown from impacts to the rest of the economy, as described in Section 5.3.

[3]Note in particular that the post-resilience model is not resilient per se, as the flood control system is still a work in progress.

4.2. CGE model elements

In this section, we provide a high-level description of the main elements of our SCGE models of Cedar Rapids. Table 1 summarizes the structure of the models, which are based on the model in Cutler and Davies (2007). Details on the productive sectors are discussed in Section 5.3. The construction of the social accounting matrices (SAMs) is based on the method developed in Cutler et al. (2017). For brevity, we provide details on the data sources used to build the Cedar Rapids SAMs for 2007 and 2015 in the Appendix.

Households represent families that live in Linn County, in either single-family homes or multi-residential dwellings, and are differentiated by income. Income groups are based on household income quantiles for each year, based on Census Public Use Microdata Sample (see the Appendix for more details). Household income consists of labor, land, and capital income. Labor income is derived from earnings within the county and wages of earners who commute out of the county. Disposable income is calculated by adding retirement flows and remittances, and subtracting taxes paid. Consumption demand is derived from a Cobb–Douglas utility function and is affected by real disposable income and relative price changes.

Firms are grouped into 29 productive sectors, as defined in Table 4. Firms demand inputs from labor, capital, and land. A constant returns to scale Cobb–Douglas production function is used for all private sectors, with first-order conditions that guarantee that private firms maximize profits by choosing optimal levels of all factors. Productive sectors also demand intermediate inputs from each other, in fixed proportions determined from IO data (see the Appendix for more details). As shown in Table 1, the housing market is also modeled as a productive sector. The housing market produces 'housing services' that demand land as an input and are differentiated primarily by whether they are located Downtown or not. In turn, households demand housing services.

The local government supplies services such as police, fire, and transportation, which require the purchase of labor. In addition, intermediate inputs are demanded in fixed proportions. The demand for factors of production is calculated in the same manner as in the productive sectors. Local government revenue is a function of a wide range of taxes related to local production, exports, imports, factor taxes, and household income. The local government also receives revenues from the state and federal governments that are modeled as transfer payments. The local government is constrained to have a balanced budget so any increase in tax revenue has to be spent on public services.

Labor, as a factor of production, is differentiated into nine labor groups based on wage quantiles. The supplies of land and capital are each treated differently. Land supply is a function of its base value times the relative returns to land and the ratio of domestic supply relative to its base. In a similar fashion, capital supply is a function of a base value of capital, relative returns to capital and the domestic supply ratio. Investment by sector of source is determined as a function of capital supply, while the total capital stock is a function of the base stock less depreciation plus the new capital supply.

Finally, note that regional economies are usually small, open economies that face considerable competition from imports and opportunities to export. In the CGE models, trade is modeled as an interaction with the 'rest of the world' (ROW). The agents in Cedar Rapids trade with both ROW consumers, of goods and services produced locally, and ROW producers, of goods and services produced outside of Cedar Rapids. We do not distinguish between trade with the rest of the United States and trade with foreign countries.

Note that because savings can easily flow in or out of the region, e.g. to help finance new investment, local savings should not be constrained. Thus net foreign savings is available as an unconstrained variable to balance trade (i.e. the difference between returns to foreign ownership of labor and capital, net exports, remittances, government transfers, and net wages from commuters).

5. Modeling Cedar Rapids

5.1. Defining the regional economy of Cedar Rapids

Cedar Rapids is the largest city in, and the county seat of, Linn County, IA. The city is an integral part of a regional economy that includes the neighboring cities of Marion, Hiawatha, Mount Vernon, and Robins, which together comprise the five most populous cities in Linn County. Given the close economic relationships between Cedar Rapids and the other cities in Linn County, this paper models the regional economy of Cedar Rapids as encompassing Linn County.

It should be noted that Linn County, along with Benton County to the west and Jones County to the east, comprise the Cedar Rapids Metropolitan Statistical Area (MSA), a much larger geographic region though not a much larger economic region. For the purposes of this paper, analyzing the regional impacts of resilience investments in the city Cedar Rapids is more appropriate at the relatively smaller scale at the county level as the impacts will dissipate quickly across county lines. For this reason, we focus on the county rather than the MSA.

5.2. Economic and demographic characteristics of the regional economy

Table 2 presents select economic and demographic characteristics for Linn County in 2007 and 2015. Note that county population and median household income are each larger in 2015 than in 2007, suggesting a stronger, more dynamic economy in 2015. The unemployment rate is slightly higher in 2015, but essentially back to pre-recession levels.

On the other hand, the aggregate number of building permits per 10,000 people (for residential buildings with 1, 2, 3–4, and 5+ units) decreased roughly 2.7% by 2015. Net new business formations, the year-over-year change in the number of business establishments per 10,000 people, also decreased by 2015. The latter two trends do not necessarily suggest underperformance in 2015 relative to 2007, but rather that the pace of residential construction and net business formation have fluctuated before, during, and after the Great Recession.[4] Meanwhile the number of building permits per capita peaked in 2009 at 55.3, bottomed out in 2011 at 32.7, and rose to 46.6 by 2015.

Table 3 presents total employment and wages paid per worker for each year, based on data from the U.S. Bureau of Labor Statistics Quarterly Census of Employment and Wages

(QCEW) for Linn County. While total employment in the Downtown area only grew by about 2.1% (compared to about 5.4% in the rest of the economy), wage per worker grew by 26.5% in the Downtown area (compared to about 22.7% in the rest of the economy). Thus while employment growth Downtown is not as large as in the rest of the economy, the relatively higher growth in wage per worker suggests labor is in higher demand in the Downtown area.

5.3. Defining the productive sectors in the regional economy

Economic development reports (Angelou Economics, 2014), as well as conversations with city officials, revealed that Cedar Rapids identified five key 'target' industries in developing a strategic economic development plan in 2014: (1) Life Science; (2) Logistics and Distribution; (3) Food Sciences and Processing; (4) Entrepreneurial Business Services; and (5) Finance, Insurance, and Real Estate.

Based on the city's self-identified target industries, as well as on the industries that are important to the Downtown area of Cedar Rapids, we define the Cedar Rapids regional economy's productive sectors as shown in Table 4. The corresponding two-digit NAICS codes and high-level NAICS industry names are also shown. The data used for the CGE models includes six-digit NAICS codes, which provide a much finer level of industry detail. As discussed in the Appendix, we define these sectors by aggregating establishment-level employment and wage data from their six-digit NAICS codes to the sectors we define in Table 4. More detail is available in Helgeson et al. (2017a).

The Core sectors are those that are important to the Downtown area. Thus economic activity in the Core sectors is distinguished spatially as occurring Downtown or outside of Downtown ('Other'). Thus we have 16 Core sectors: 8 Downtown and 8 in Other.

The remaining sectors are those for which we do not distinguish economic activity spatially. Thus we have 13 sectors for which economic activity may take place anywhere in the economy. The total number of productive sectors in the model is therefore 29 (16 spatial sectors + 13 non-spatial sectors).

5.4. Structural differences between 2007 and 2015

We construct and calibrate two SAMs for Linn County with the structure as shown in Table 1, one using data for 2007 and the other for 2015. Each represents a snapshot of the regional economy of Cedar Rapids, one before the floods of 2008, and the other after the floods and initial investments in increased resilience. Before we consider how each economy responds to a shock, it is worth investigating structural differences between each CGE model. Such differences are likely to drive any observed differences in response to the shock.

Consider the following general production function:

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[4]Indeed, as shown in Appendix Figure 6, annual data from 2000 to 2016 shows that net new business formation was negative between 2001 and 2002 and peaked in 2004 at 2.1% before going negative again after the Great Recession and fluctuating between 1% and 2% from 2012 onward.

$$Y_i = \delta_i F\left(L_{ij}, K_i, LA_i\right) \tag{1}$$

where Y is the output, i is the index across commercial sectors, j is the index across labor groups, L is the employment, K is the capital, and LA is the land. The term δ_i represents sector-level total factor productivity (TFP). In the construction of the SAM, we have collected data for L, K and LA and then we calculate sector-level output, Y_i. Therefore, we can solve for δ_i as

$$\delta_i = \frac{Y_i}{F\left(L_{ij}, K_i, LA_i\right)} \tag{2}$$

Each term δ_i measures shifts in the production function for sector i, given factors of production, and is typically associated with technical capacity (Hulten, 2001). The initial values for δ_i have important implications when shocks are simulated. A larger initial value of δ_i implies that a given positive shock to δ_i will result in a larger impact on sector level output. The differential impacts from the same shock reflect the relative difference of the initial δ_i's across the two time periods.

Table 5 presents base data ('status quo') estimates of δ_i for 2015 and 2007 aggregated by sector of interest, as well as each aggregate sector's contribution to total TFP.[5] The Core sectors aggregate the spatialized sectors identified in Table 4, depending on whether firms are located Downtown or the rest of the economy ('Other'). Remaining sectors aggregate the non-spatialized sectors.

Note that total TFP is 37.1% higher in 2015 than in 2007. Much of the differences come from the Core sectors, both within Downtown (72.7% higher in 2015) and outside of Downtown (73.6% higher in 2015). For the remaining sectors, TFP is 12.3% higher in 2015. Perhaps more telling is the contribution to total TFP from the Core sectors. In 2007, Core (Downtown) accounts for 21% of total TFP, while in 2015 it accounts for over 26%. Core (Downtown) accounts for 20% of total TFP in 2007, while it accounts for 25% of total TFP in 2015. On the other hand, the remaining sectors account for a larger fraction of total TFP in 2007 (59%) than in 2015 (49%). In other words, the Core sectors became more productive in 2015, both in Downtown and outside of Downtown.

The vast majority of sectors experienced an increase in the estimated δ_i from 2007 to 2015. In particular, finance-insurance and professional business services, two of the city's target sectors, experience significant productivity gains. In the Downtown area, δ_i increased from 0.329 to 1.751 for finance-insurance and from 0.448 to 0.659 for professional business services. Outside of Downtown, δ_i increased from 0.284 to 1.703 for finance-insurance and from 0.491 to 0.630 for professional business services.

The higher initial productivity core sectors, especially Downtown, is reflected in the larger initial contribution to total output from the core sectors, as shown in Table 6. Core sectors in the Downtown area account for 3.4% of total output in 2007 and 4.5% of total output in

[5]Unaggregated values are available from the authors upon request.

2015, over a percentage point higher. Core sectors outside of Downtown account for 20% of total output in 2007 and 26% of total output in 2015. This implies a reduced share of total output coming from the remaining sectors. The larger changes in output in 2015 relative to 2007 in part reflect the larger contribution to total output coming from the core sectors, especially Downtown.

As the discussion in Section 3 illustrates, the neighborhood revitalization that took place in Cedar Rapids after the floods was paramount to other changes during this period. As Table 5 indicates, the expansion of Downtown for services increased Downtown productivity, δ_i. This is consistent with a denser allocation of commercial sectors in the Downtown area and the resulting higher values for δ_i, a phenomenon known as 'agglomeration'. Moreover, most of the estimates for δ_i also increased for the core sectors located outside of Downtown, which implies positive spillovers for the rest of the economy from the revitalization of Downtown and also reflects the city's focus on growing its target sectors. In summary, for the same shock to each economy, we expect that the higher values for δ_i in 2015 will result in a larger increase in sector level output and total output for the 2015 model relative to the 2007 model.

6. Main results: quantifying resilience dividends

In this section, we quantify the co-benefits from investing in increased resilience. To set the stage, we first consider the impact of a disaster-related shock to Cedar Rapids in order to quantify avoided losses. In particular, we simulate a flood event that damages the capital stock in pre-resilience Cedar Rapids. The caveat is that the seven-mile flood-control system in Cedar Rapids is a long-term capital project. As of 2015, Cedar Rapids had invested in a voluntary property acquisition program, a new amphitheater that doubles as a levee, raising the city's water wells, and, of course, neighborhood revitalization (City of Cedar Rapids, 2020b). Thus our simulated shock focuses on the actions taken as of 2015.

In order to quantify the co-benefits from these investments, we compare how pre- and post-resilience Cedar Rapids respond to the same exogenous *non-disaster* shock. A differential response in post-resilience Cedar Rapids, relative to pre-resilience Cedar Rapids, to the same shock can be largely attributed to investing in resilience – in particular, to the largest investment to date, neighborhood revitalization. The differences in response represent the net co-benefits that accrue in the absence of a natural disaster.

In the following sections, we discuss the impacts of each shock on three macroeconomic outcomes of key interest: real output, which is measured by domestic supply and captures how much the local economy produces (i.e. local GDP); total employment, which simply measures how many people are employed in the local labor force; and real household income, which includes all wage payments, transfers, and other income earned by households. Note that this is not intended to be an exhaustive list of all the potential benefits and co-benefits of investing in increased resilience. Rather, they provide a high-level picture of the net benefits for the economy as a whole, as well as how those benefits are distributed throughout the economy.

For ease of presentation, we present results in terms of high-level aggregate sectors. In particular, we consider the following key aggregate sectors:

- Core sectors (Downtown or Other) aggregate the spatialized sectors identified in Table 4, depending on whether they are located Downtown or not;
- Remaining sectors aggregate the non-spatialized sectors identified in Table 4;
- HS (Downtown or Other) aggregate housing services, depending on whether they are located Downtown or not.

Where appropriate, we also consider the aggregate government sector (e.g. government employment includes federal, state, and local governments). Unaggregated results are presented in the Appendix and provide a more detailed picture of how co-benefits are distributed across specific sectors and household groups.

6.1. Avoided losses

In this section, we quantify avoided losses from the investments in increased resilience made by Cedar Rapids. Given the actions undertaken as of 2015, the acquisition of 1356 flood-prone properties represents the most significant step toward direct risk mitigation. Thus we simulate a flood event that damages the flood-prone properties in *pre-resilience* Cedar Rapids. The avoided losses in post-resilience Cedar Rapids are simply the losses from the flood event in pre-resilience Cedar Rapids, since those properties no longer exist and therefore cannot be damaged. This is analogous to the ‘first dividend of resilience’ in Tanner et al. (2015), Mechler et al. (2016), and Vorhies and Wilkinson (2016).

The ultimate objective of the voluntary property acquisition, or ‘buyout’, program is to reduce flood risk by rezoning areas of the city that are vulnerable to river flooding as either green space or wetlands (Tate et al., 2016). The program was funded through a combination of grants from the FEMA Hazard Mitigation Grant Program (HMGP) and the U.S. Department of Housing and Urban Development Community Development Block Grant (HUD CDBG) Program (City of Cedar Rapids, 2020b). As of 2015, all acquired parcels remained undeveloped.

Of the 1356 properties acquired through the buyout program, 1,183 were on residential parcels on the west side of the Cedar River, within the 100-year floodplain. The remaining acquisitions consisted of vacant, tax-exempt, and commercial parcels. The roughly 150 commercial parcels that were acquired were scattered along different parts of the city, along both the east and west sides of the Cedar River. This is in contrast to the residential parcels, which were all clustered in one area on the west side of the river.

In the simulation, we therefore focus on the 1,183 residential parcels, most of which provide housing services in HS1, the first quartile of the housing services sector. Without loss of generality, we assume all of the acquired parcels provide services in HS1.[6] Given 17,984

[6]Recall that residential properties are allocated to a housing services sector based on assessed property value quartiles. While some of the acquired properties had property values that placed them in higher quartiles,we assume they all belong to the first quartile for simplicity. Atworst, this implies our results are biased downward, i.e. the avoided losses are expected to be higher for properties with higher property values.

total properties in HS1, the acquired parcels account for 1,183/17,984 = 0.0658 of HS1. Thus we simulate the flood event by reducing the capital stock in HS1 by 6.58%.

Table 7 presents the results of the simulated flood event. In percentage change terms, the losses do not appear large: −0.08% in lost output, −0.1% in lost employment, and −0.09% in lost household income. In absolute terms, the losses are $5.95 million in lost output and $2.8 million in lost income. Moreover, 93 jobs are lost. Since the damaged parcels were acquired by the city and remained undeveloped in 2015, these amount to the avoided losses in post-resilience Cedar Rapids. It is worth noting that 1,183 homes is a small percentage of the housing stock in Cedar Rapids.

One advantage of our spatial CGE model is that we can quantify how losses are distributed throughout the economy. Note that while housing services in the Downtown area are largely unaffected, housing services in the rest of the economy lose $3.1 million in output. Moreover, output in the Core sectors in the Downtown area lose $0.1 million in output, while the Core sectors in the rest of the economy lose $1.1 million in output. Additionally, most of the job losses occur in the Core sectors outside of Downtown, with 50 jobs lost, and the remaining sectors, with 36 jobs lost.

Finally, the distribution of income losses is revealing. The largest impact in both absolute and percentage change terms is on middle-income households, which lose $2.9 million in real household income. Interestingly, high-income households experience a $0.2 million gain in real income, likely because the reallocation of capital following the flood benefits higher income households.

In the future, some of this land will be redeveloped to double as public space or wetlands, thus providing both long-term avoided losses from disaster risk mitigation as well as additional co-benefits from providing public good amenities, analogous to the “third dividend of resilience” (Tanner et al., 2015). Moreover, as additional elements of the flood-control system are built, the avoided losses are expected to increase.

However, given the investments made in the short time between the flood and 2015, we do not expect that Cedar Rapids should be fully protected from the impacts of flooding by 2015. Indeed, on Tuesday, 27 September 2016, the Cedar River reached its second-highest crest ever at 22 feet (Munson, 2016). Fortunately, city officials were able to mobilize quickly in anticipation of the flooding, setting up 10 miles of temporary flood barriers, including earthen berms and sandbags. If the river had crested a few feet higher, the temporary barriers would not have prevented catastrophic flooding.

Thus our simulated flood event provides a measure of how much more ‘resilient’ Cedar Rapids has become from the limited investments made as of 2015. This includes securing funding for the flood control system, which signals to businesses that Cedar Rapids, particularly downtown, is a safe economic environment.

6.2. Co-benefits for the economy

In this section, we quantify the economic co-benefits from investing in increased resilience – in particular, in neighborhood revitalization – that accrue in the absence of a natural disaster, analogous to the "second dividend of resilience" (Tanner et al., 2015). To quantify these co-benefits, we consider exogenous shocks to population growth, export demand, and total factor productivity (TFP), which represent important sources of growth for small regional economies (Burnett et al., 2012). We investigate whether post-resilience Cedar Rapids is better positioned to reap the benefits from the same positive shock than pre-resilience Cedar Rapids.

First, we consider an exogenous population increase. Assuming one of the goals of neighborhood revitalization is to both keep current residents and to attract new residents, a natural question whether post-resilience Cedar Rapids can better absorb a larger population than pre-resilience Cedar Rapids. To simulate the shock, we increase the natural rate of population growth parameter in each model. The natural rate of population growth parameter governs both the replacement rate in terms of births net deaths as well as in-and outmigration.

Table 8 presents the impact of an exogenous 2% increase in population growth for each of the models of Cedar Rapids. Across all sectors, real output increases by 0.6% in 2015, compared to 0.45% growth in 2007. Thus post-resilience Cedar Rapids benefits from the shock by an additional 0.16% in output growth relative to pre-resilience Cedar Rapids, which represents the resilience dividend for output. The table also illustrates how the resilience dividend is distributed throughout the sectors of the economy. Note that each aggregate sector experiences at least 0.1% more output growth in post-resilience Cedar Rapids. The remaining sectors (the non-spatial sectors) experience 0.2% higher output growth in 2015. Finally, the resilience dividends for housing services are also positive, with housing services Downtown experiencing 0.1% more growth in 2015 and housing services in the rest of the economy experiencing 0.2% more growth in 2015.

Employment growth, on the other hand, is the same in both economies, resulting in a resilience dividend of zero. Note the distribution of co-benefits demonstrates 0.1% lower growth in the Core sectors for post-resilience Cedar Rapids relative to pre-resilience Cedar Rapids, implying that the Core sectors are more efficient in 2015 as they produce more output per worker. Employment in the remaining (non-spatial) sectors experiences 0.1% higher growth in post-resilience Cedar Rapids, with government employment increasing by 0.3%.

Finally, the resilience dividend for household income is 0.08%, with real income growth of 0.2% in post-resilience Cedar Rapids and 0.1% in pre-resilience Cedar Rapids. The distribution of co-benefits is not uniform across household groups. Low-income households gain 0.1% less in 2015 than in 2007, while medium-income households experience roughly the same gain. On the other hand, high-income households gain 0.1% more in 2015 than in 2007.

The results can be explained by the higher productivity of post-resilience Cedar Rapids, as shown in Table 5. Recall that total TFP in the base data is 37% higher in 2015 than in 2007, largely driven by the higher productivity of the Core sectors. In fact, two of the city's self-identified target industries – professional business services (PBS) and finance-insurance – are much more productive.

To illustrate the productivity gains, we simulate an exogenous shock that affects an individual target sector. Table 9 presents the results of the simulations. Note that the sectors are distinguished spatially depending on whether economic activity occurs Downtown or in the rest of the economy (‘Other’). Thus we have eight simulations (2 shocks ×2 sectors ×2 spatial units). As Table 9 illustrates, Professional Business Services (PBS) and Finance-Insurance experience largely positive resilience dividends both in Downtown and in Other, where the dividends are obtained as the difference in growth rates between 2015 and 2007.

Since the units of measurement vary across outcomes, it is difficult to quantify a ‘grand total’ resilience dividend (for instance, does 0.16% net total output growth outweigh −0.1% net employment growth in the Core sectors?). Nevertheless, the results suggest that, on the whole, the net co-benefits of investing in neighborhood revitalization, as well as in PBS and finance-insurance, are positive. In practice, policy makers and other stakeholders may only care about one or two of these outcomes. On the other hand, one could imagine collecting such resilience dividends into a ‘portfolio’ and weighing them by importance.

Finally, we note that the new amphitheater, which doubles as a levee, likely yields some additional co-benefits for the economy in terms of amenity value, analogous to the “third dividend of resilience” (Mechler et al., 2016; Tanner et al., 2015; Vorhies & Wilkinson, 2016). The McGrath Amphitheatre, with a maximum capacity of 5000 people, opened in 2013 as the first segment of the flood control system on the west bank of the Cedar River (City of Cedar Rapids, 2020c). The dual-purpose amphitheater is “[d]esigned to take on water ... [and] also provides a signature outdoor concert and event venue” (City of Cedar Rapids, 2020b). However, the quantification of co-benefits from the amphitheater is outside the scope of the CGE approach presented in this paper. In particular, quantifying the amenity value of a dual use levee would require revealed preference (e.g. hedonic analysis of property values near such dual use levees) or stated preference (e.g. a survey to elicit willingness-to-pay for such dual use levees) methods to supplement the construction of the SAM. Moreover, based on conversations with city officials we concluded that the amenity value for the amphitheater is much smaller in magnitude relative to, for instance, neighborhood revitalization and is likely to be washed out in a CGE analysis. Thus, while we believe the amphitheater provides additional positive co-benefits, we do not quantify them.

6.3. Are the dividends due to resilience?

Finally, it is worth considering other economic changes between 2007 and 2015, such as the Great Recession, that could be driving the differential response observed in post-resilience Cedar Rapids. While some firms across many became more capital intensive after the recession, the U.S. Bureau of Labor Statistics (BLS) reports that the average annual growth in TFP was 1.25% from 2000 to 2007 but only 0.4% during the 2007–2018 period.[7] The fact

[7]Source: Bureau of Labor Statistics (BLS) Multifactor Productivity (MFP) Tables https://www.bls.gov/mfp/mprdload.htm

that TFP in Cedar Rapids grew by 37% between 2007 and 2015, as shown in Table 5 in Section 5.4, is consistent with the unique programs implemented by Cedar Rapids.

However, some multicollinearity does exist between the Great Recession and the 2008 flood. As discussed in Section 5.1 and shown in Appendix Figure 6, growth in Linn County for net new businesses is roughly negative in the period 2007–2011. After 2011, growth turns positive and recovers the pre-recession rate by 2016. One explanation for the observed trend is that the Great Recession, as well as the 2008 floods, 'accelerated' the failure of already failing firms, creating opportunities for more productive firms to enter the market and succeed. As examples see Alesch et al. (2001) and Chang (2010), who conclude that new firms replace older firms following a natural disaster.

In the case of Downtown Cedar Rapids in particular, this was partly by design, as the City saw an opportunity after the floods of 2008 to redevelop Downtown properties that were being used by failing businesses. We do not claim that investing in increased resilience is the sole driver of our results. However, it is difficult to disentangle the impacts of the devastating flood and the impacts of the Great Recession from efficient city management, which may just be the unobserved factor driving our results.

Improved resilience through targeted investments constitutes an important signaling device for the future economic success of a community by demonstrating a credible commitment, in the spirit of North (1993). Local leadership and institutions can act proactively to mitigate the potential harm from future hazards. These efforts can reduce the uncertainty around investment decisions of businesses and residents in the region who might otherwise worry about the longevity of local economic opportunities. If expectations about the efficacy of future flood mitigation and resilience enhancing investments in Cedar Rapids induce greater investment by firms, growth will be increased, and resilience and growth will become inseparable.

7. Conclusion

This paper presents a spatial CGE approach to quantifying resilience dividends. We build two snapshots of Cedar Rapids (pre-resilience and post-resilience) that serve as counterfactuals of an economy with and without investments in increased resilience, respectively. The primary structural difference between the two snapshots is higher aggregate and sector-level TFP values in 2015. By simulating the same shock in each snapshot, we quantify how impacts differ in post-resilience versus pre-resilience Cedar Rapids. We find that the same increase in population growth leads to a larger response in output, employment, and income for post-resilience Cedar Rapids. The differential responses quantify the resilience dividends from the shock, which are benefits to the local economy in the absence of a disaster. Moreover, our results demonstrate how co-benefits are distributed across sectors and across households. Finally, export demand and TFP shocks illustrate that the city's target industries are thriving in post-resilience Cedar Rapids.

While our results demonstrate how resilience dividends are distributed across the economy, the picture we obtain only captures 'aggregate' macroeconomic impacts. Thus, for instance, while we can observe responses at the sector level, we cannot say anything about which firms in a sector are gaining more from the shocks. Moreover, while we can identify impacts within the Downtown area or on the rest of the economy, we cannot identify responses by neighborhood or any finer scale. Nevertheless, aggregate impacts are useful for demonstrating that investing in resilience has benefits that accrue in the absence of a disaster.

In future work, we will consider resilience in Cedar Rapids following additional investments. Since the Flood Control System Master Plan was adopted in 2015, Cedar Rapids has completed two new levees, two new pump stations, and a floodwall, and began construction on additional levees, pump stations, floodwalls and flood gates, as well as additional projects addressing road and bridge improvements (City of Cedar Rapids, 2020a, 2020b). It would be worthwhile to quantify both the resilience and any resilience dividends from these additional investments that more directly address flood risk. This is left for future work.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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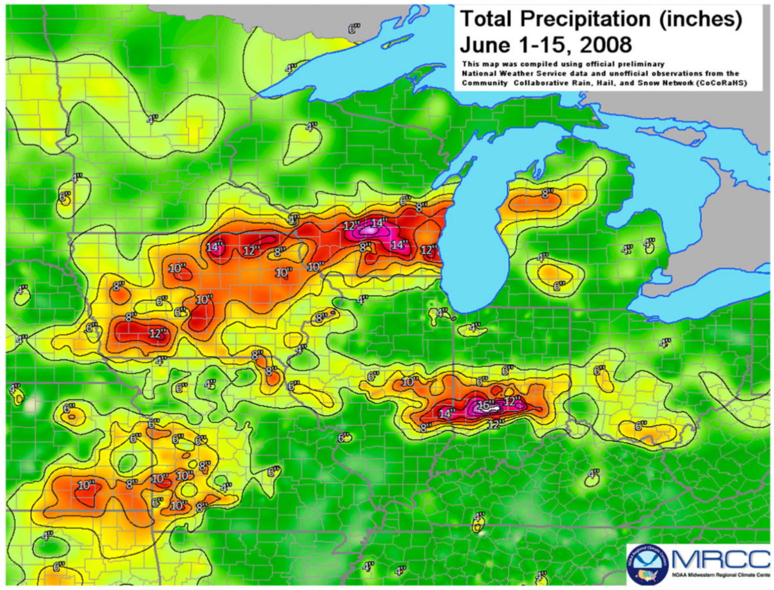

Figure 1.

Total precipitation during the period of 1–15 June 2008. Parts of Indiana, Illinois, Iowa, and Wisconsin received a foot or more of precipitation.

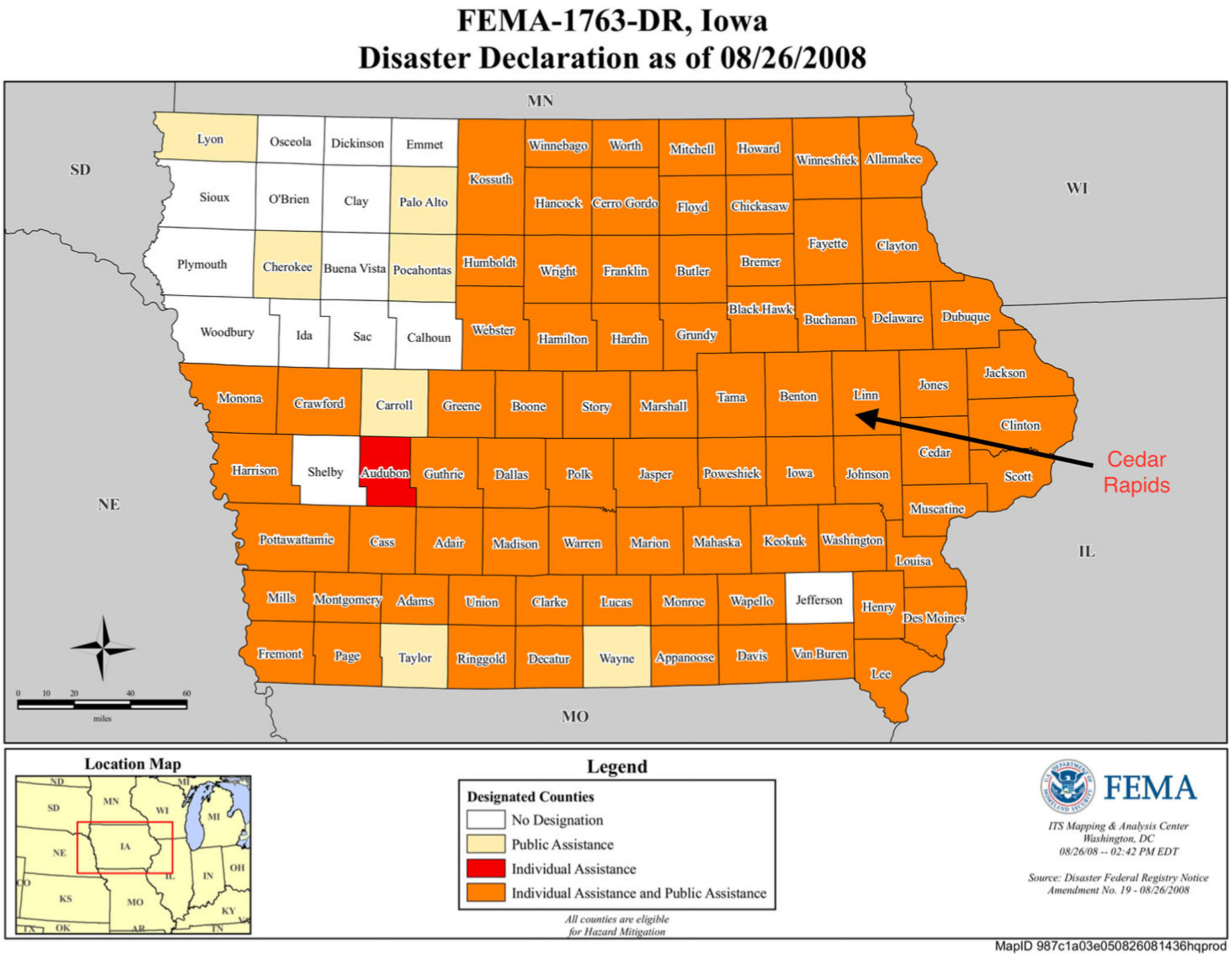

Figure 2.

Disaster Declaration 1763 covered 85 of Iowa's 99 counties following the June 2008 floods, with approximate location of Cedar Rapids in Linn County.

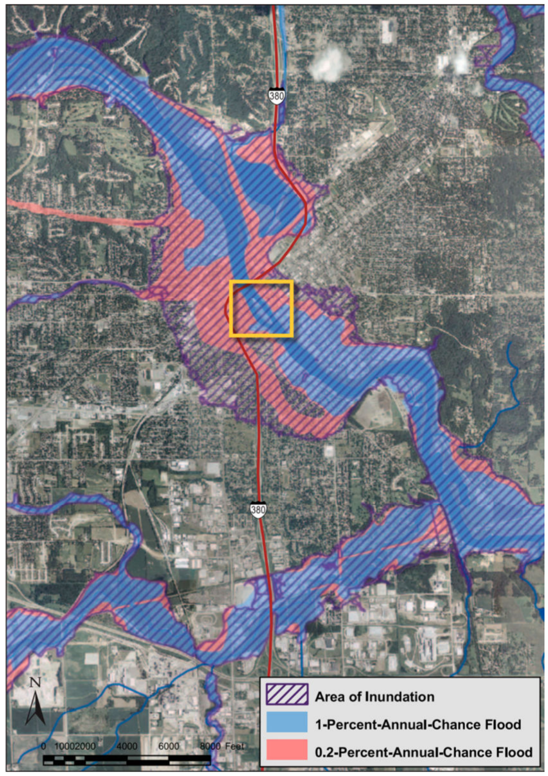

Figure 3.
Map illustrating flood inundation area along the Cedar River in Cedar Rapids, IA. The downtown area, including May's Island, is highlighted by the yellow box.

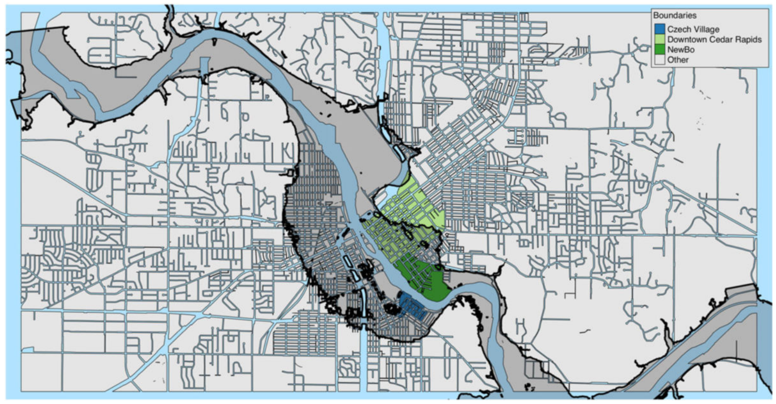

Figure 4.

Detail of ‘Downtown’ neighborhoods and extent of the 2008 flood (dark grey shading with black boundary). Map created using City of Cedar Rapids shapefiles.

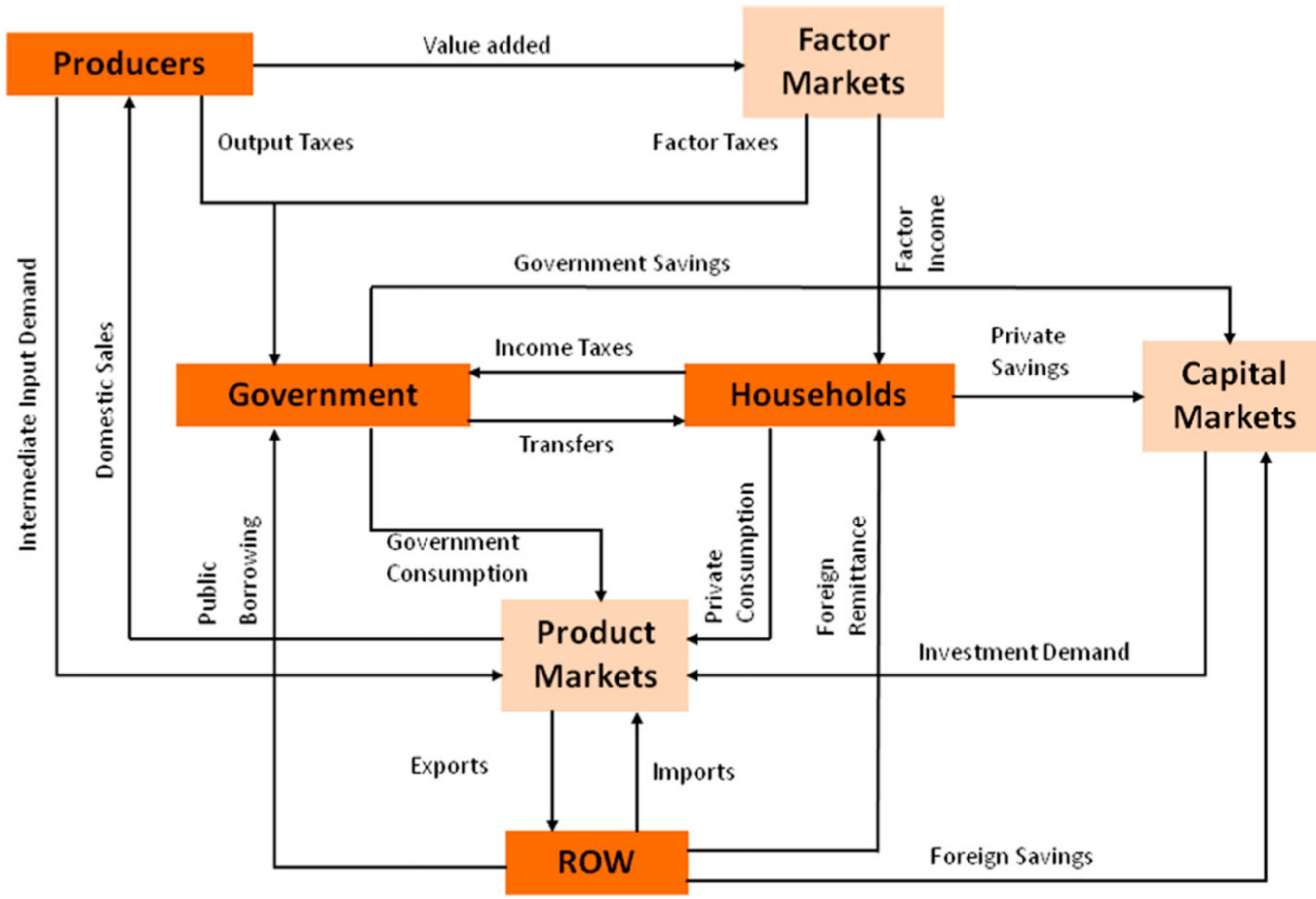

Figure 5.
Schematic of CGE model elements, where 'ROW' refers to the Rest of the World, as described in more detail in Section 4.2.

Table 1.

Structure of the SCGE models. The local economy represents Linn County, which includes Cedar Rapids as the largest city.

Households	Nine household groups - differentiated by income quantiles
Firms	29 productive sectors - see Table 4
Housing market	Seven 'Housing Services' sectors: - One sector in each of Downtown, Czech Village, and NewBo - Four sectors in Other, differentiated by property value quartiles
Local government	- Provides services (e.g. police) - Demands labor and intermediate goods from private sector
Factors of production	- Labor - Capital - Land
Rest of the World (ROW)	Models trade outside of the local economy

Table 2.

Economic indicators for Linn County, for 2007 and 2015.

Indicator	2007	2015
Population	204,995	219,971
Median Household Income	53,076.00	58,142.00
Building Permits (per 10,000 people)	5.45	4.66
Net New Business Formations (per 10,000 people)	1.0%	0.6%
Unemployment Rate	3.7%	3.8%

Source: Economic Resilience and Inclusion Navigator (ERIN), produced by the Community Development department at the Federal Reserve Bank of St. Louis and available at https://bsr.stlouisfed.org/ERIN//Home.

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Table 3.

Employment (number of workers) and annual wage per worker (in dollars) for the downtown area (Downtown Cedar Rapids, NewBo, and Czech Village) and the rest of the regional economy by year, based on the QCEW for the Linn County, Iowa.

Region	Year	Employment	Change	Wages	Change
Downtown	2015	5924	2.1%	14,230.58	26.5%
	2007	5801		11,244.89	
Other	2015	121,296	5.4%	12,951.05	22.6%
	2007	115,080		10,556.87	

Table 4.

Productive sectors defined in the CGE models. For the eight ‘Core’ sectors, economic activity is separated spatially between ‘Downtown’ and the rest of the economy, for a total of 16 Core sectors. The remaining 13 sectors are not differentiated spatially. The total number of productive sectors in the models is therefore 29.

Sector	NAICS industry	NAICS code
Core sectors		
Finance and insurance	Finance and Insurance	52
Real estate	Real Estate Rental and Leasing	53
Professional services	Professional, Scientific and Technical Services	54
	Management of Companies and Enterprises	55
Other services	Administrative and Support Services	56
	Other Services (except Public Administration)	8
Arts and entertainment	Arts, Entertainment, and Recreation	71
Accommodation	Accommodation and Food Services	72
Restaurants	Accommodation and Food Services	72
Retail	Retail Trade	44–45
Remaining sectors		
Electronics	Manufacturing	33
Food processing	Manufacturing	31
Paper	Manufacturing	32
Other manufacturing	Manufacturing	31–33
Construction	Construction	23
Transportation	Transportation and Warehousing	48–49
Online services	Retail Trade	45
	Transportation and Warehousing	49
Education	Educational Services	61
Health care	Health Care and Social Assistance	62
Wholesale trade	Wholesale Trade	42
Information	Information	51
Agriculture and mining	Agriculture, Forestry, Fishing and Hunting	11
	Mining	21
Utilities	Utilities	22

Table 5.

Base data values of δ_i aggregated by sector and the contribution to total TFP by sector for 2015 ('post-resilience') Cedar Rapids and 2007 ('pre-resilience') Cedar Rapids.

	2007		2015		
Sector	δ_i	**% of total TFP**	δ_i	**% of total TFP**	**Growth**
Core (Downtown)	3.125	20.92%	5.398	26.36%	72.7%
Core (Other)	2.964	19.84%	5.146	25.13%	73.6%
Remaining sectors	8.850	59.24%	9.936	48.51%	12.3%
All sectors	14.939	–	20.480	–	37.1%

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Table 6.

Base data values of sector-level output (in millions of dollars) and the contribution to total output by sector for 2015 ('post-resilience') Cedar Rapids and 2007 ('pre-resilience') Cedar Rapids.

	2007		2015	
Sector	**Output**	**% of total output**	**Output**	**% of total output**
Core (Downtown)	240.88	3.36%	580.77	4.45%
Core (Other)	1439.95	20.10%	3358.36	25.74%
Remaining sectors	5490.35	76.56%	9109.60	69.81%
All sectors	7171.19	–	13,048.73	–

Table 7.

Impacts of simulated flood event in 2007 ('pre-resilience') Cedar Rapids on real output (domestic supply in millions of dollars), total employment, and real household income (in millions of dollars). The table presents levels before and after the shock, as well as the level and percentage change. These are the economic losses.

	2007			
	Pre	**Post**	**Level change**	**Percent change**
Output	7171.2	7165.23	−5.95	−0.08%
Output by sector				
Core (Downtown)	240.9	240.8	−0.1	−0.04%
Core (Other)	1439.9	1438.9	−1.1	−0.08%
HS (Downtown)	1.97	1.97	0.0	0.0%
HS (Other)	981.2	978.1	−3.1	−0.03%
Remaining sectors	4507.2	4505.6	−1.7	−0.04%
Employment	95,034	94,941	−93	−0.10%
Employment by sector				
Core (Downtown)	5587	5581	−6	−0.01
Core (Other)	37,843	37,793	−50	−0.01%
Government	1671	1669	−2	−0.1%
Remaining sectors	49,933	49,897	−36	−0.1%
Income	3213.0	3210.2	−2.8	−0.09%
Income by household group				
Low income	110.7	110.6	−0.1	−0.1%
Medium income	1146.8	1143.9	−2.9	−0.2%
High income	1955.5	1955.7	0.2	0.01%

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Table 8.

Impacts of population growth shock on real output (domestic supply in millions of dollars), total employment, and real household income (in millions of dollars). The table presents levels before and after the shock, as well as the percentage change. The resilience dividend is the net growth in each outcome in 2015 (‘post-resilience’) Cedar Rapids relative to 2007 (‘pre-resilience’) Cedar Rapids. Note that values may not sum due to rounding.

	2007			2015			
	Pre	**Post**	**Change**	**Pre**	**Post**	**Change**	**Resilience dividend**
Output	7171.2	7203.4	0.45%	13,048.7	13,127.7	0.60%	**0**.16%
Output by sector							
Core (Downtown)	240.9	241.8	0.4%	580.8	583.8	0.5%	0.1%
Core (Other)	1439.9	1447.9	0.6%	3358.4	3381.4	0.7%	0.1%
Remaining sectors	4507.2	4529.8	0.5%	7295.6	7343.9	0.7%	0.2%
HS (Downtown)	1.97	1.98	0.1%	6.02	6.03	0.2%	0.1%
HS (Other)	981.2	981.9	0.1%	1807.0	1812.5	0.3%	0.2%
Employment	95,034	95,806	0.8%	122,348	123,339	0.8%	**0**.00%
Employment by sector							
Core (Downtown)	5587	5629	0.7%	5999	6037	0.6%	−0.1%
Core (Other)	37,843	38,185	0.9%	46,327	46,710	0.8%	−0.1%
Remaining sectors	49,933	50,307	0.7%	67,832	68,376	0.8%	−0.1%
Government	1671	1685	0.8%	2190	2213	1.1%	0.3%
Income	3213.0	3217.8	0.1%	6048.6	6062.6	0.2%	**0**.08%
Income by household group							
Low income	110.7	111.2	0.5%	469.5	471.5	0.4%	−0.1%
Medium income	1146.8	1151.0	0.4%	2190.0	2197.7	0.4%	0.0%
High income	1955.5	1955.5	0.0%	3389.1	3393.4	0.1%	0.1%

Table 9.

Impacts on real output (domestic supply in millions of dollars), total employment, and real household income (in millions of dollars) of a 2% export demand shock and a 2% TFP shock that each affects an individual target industry. The resilience dividend is the difference in response in 'post-resilience' Cedar Rapids relative to 'pre-resilience' Cedar Rapids.

	Export demand		TFP	
	PBS	**Finance-insurance**	**PBS**	**Finance-insurance**
Downtown				
Output				
2007	0.00%	0.00%	0.00%	0.00%
2015	0.02%	0.02%	0.05%	0.034%
Dividend	0.14%	0.024%	0.044%	0.038%
Employment				
2007	0.01%	0.01%	0.01%	0.01%
2015	0.02%	0.02%	0.04%	0.017%
Dividend	0.18%	0.013%	0.039%	0.009%
Income				
2007	0.01%	0.00%	0.01%	0.00%
2015	0.04%	0.03%	0.04%	0.012%
Dividend	0.037%	0.026%	0.031%	0.010%
Other				
Output				
2007	0.01%	−0.02%	0.05%	0.03%
2015	0.03%	0.09%	0.12%	0.14%
Dividend	0.018%	0.111%	0.073%	0.110%
Employment				
2007	0.02%	0.03%	0.04%	0.00%
2015	0.05%	0.10%	0.04%	0.02%
Dividend	0.024%	0.070%	0.000%	−0.016%
Income				
2007	0.03%	0.02%	0.04%	0.01%
2015	0.08%	0.13%	0.07%	0.00%
Dividend	0.055%	0.117%	0.036%	−0.008%