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Incorporating Economic Resilience Metrics into INDOT's Transportation Decision-Making

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16. Abstract

The 2007 Great Recession is widely considered the worst economic downturn in recent United States History. In Indiana, the unemployment rate reached 10.6%, and took nearly seven years to return to pre-recession levels. However, employment data from this period shows that the change in total employment at the county level ranged from -20% to +5%, indicating that while many counties suffered from high unemployment, other counties experienced gains in total employment. Various research efforts, including this project, have been undertaken to understand the local characteristics that influence the differing degrees to which regional/city economies were able to resist or cope with the effects of the recession. In the literature, this ability is referred to as regional economic resilience (RER).

This research project's primary objective is to develop a framework and tool that could be used by INDOT's Asset Planning & Management Division and Indiana metropolitan planning organizations (MPOs) to evaluate the role of transportation accessibility in building RER of Indiana's regions to economic shocks. The following tasks were undertaken: the development of a resilience index to inform stakeholders of the comparative RERs in Indiana; the estimation of an econometric model to evaluate the association between Indiana counties' regional characteristics and the resilience index; the development of a framework in which results of previous tasks can be incorporated into transportation decision-making at the sketch level by MPOs, regional development organizations, and other similar agencies; and design of a tool to allow planners to examine the potential changes to RER due to policies or other exogenous shocks.

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EXECUTIVE SUMMARY

Introduction

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This research project's primary objective was to develop a framework and tool that could be used by INDOT's Asset Planning and Management Division and Indiana metropolitan planning organizations (MPOs) to evaluate the role of transportation accessibility in strengthening the capacity of regions in Indiana in resisting economic shocks. The following tasks were undertaken:

- the development of a resilience index to inform stakeholders of the comparative RERs in Indiana;
- the estimation of an econometric model to evaluate the association between Indiana counties' regional characteristics and the resilience index;
- the development of a framework in which results of previous tasks can be incorporated into transportation decision-making at the sketch level by MPOs, regional development organizations, and other similar agencies; and
- the design of a tool to allow planners to examine the potential changes to RER due to policies or other exogenous shocks.

Study Framework

In order to develop a resilience index, the project asked a panel of experts for their opinions on how various factors (latent variables) influenced RER. These factors were identified via an extensive literature review process. The questionnaire responses formed the basis of the weighting system used to calculate the resilience index. Concurrently, an econometric model was constructed using data from the U.S. Census Bureau, among others, to determine the extent to which observed variables (e.g., population within 180 minutes) influenced the latent variables (e.g., transportation accessibility). The results from the empirical model were then used in the development of the planning tool. The tool consists of a dashboard allowing users to compare RERs between regions, a micro-simulation component to evaluate changes to RER at a policy level, and a macro-simulation component to evaluate changes to RER at a project's sketch-planning level.

Recommendations/Implementation

The deliverables stemming from this project can be used to help inform policy makers and transportation planners at the metropolitan, county/regional, and state levels with empirically driven predictions of how potential projects will affect RER. Stakeholders can use this information to develop more robust benefit cost analyses to evaluate potential projects or policy interventions as part of a multiple criteria decision-making process. Furthermore, because of the multitude of factors incorporated within the RER estimator spreadsheet tool, potential projects are not limited to solely traditional transportation projects such as improvements to highway infrastructure or increasing labor market access. Another potential use of the tool is to evaluate the impact of multiple interventions simultaneously on RER.

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1. INTRODUCTION

1.1 Motivation

The 2007 recession is considered the worst economic downturn in post-war United States (U.S.) history (Elsby et al., 2010). For Indiana, it meant a statewide average unemployment rate as high as 10.6% (June 2009) and took approximately seven years (i.e., July 2014) to recover from (Kinghorn, 2015). Although the study of economic fluctuations has a long history (Martin et al., 2016), their potential negative effects are always relevant as scholars have noted that the U.S. has undergone at least one official recession or depression every decade (Johnson, 2013). In addition, the literature points out that the effects of recessions are not equally distributed across socio-economic groups or geographical regions. In Indiana, employment data from the 2007–2009 Great Recession shows that the change in total employment at the county level ranged from -20% to +5% (between 2007 and 2009). Because the aggregated state trends in employment are simply a reflection of the capacity of local and regional economies to resist and recover from the effects of recessions (Martin et al., 2016), various research efforts have been undertaken to understand the local characteristics that influence the aggregated regional resilience capacity of urban and regional economies. The regional/city economies that were able to resist or cope with the effects of a recession are labeled as "resilient," a term that has become an ideal objective for policy making and planning, just as sustainability or social justice. For that reason, there is also a significant body of research conceptualizing regional resilience. The wide body of literature on the concept and factors of resilience, however, presents little evidence of the role that infrastructure systems, particularly transportation infrastructure, play in building more resilient regions.

1.2 Objectives

In view of the above, this study aims to understand the most important regional factors that influenced the spatial distribution of the recession's effects in Indiana with a special attention on transportation infrastructure. Specifically, the objective of this project is to develop a framework and tool that could be used by the INDOT's Asset Planning and Management Division and Indiana Metropolitan Planning Organizations to evaluate the role of transportation accessibility in strengthening the capacity of regions in Indiana in resisting economic shocks. The specific tasks are as follows:

1. Develop a resilience index to better inform stakeholders of the comparative RER in Indiana with respect to planning the implementation of potential transportation projects.
2. Develop an econometric model that can evaluate the association between Indiana Counties' regional characteristics, including transportation accessibility, and the resilience index developed under Task 1.
3. Develop a framework in which the results of the previous steps can be incorporated into transportation decision-making at the sketch-level by Metropolitan Planning Organizations (MPO), Regional Development Organizations (RDOS), and other similar agencies.
4. Create a tool based on the framework from Task 3 to allow planners to examine the ways that changes from policies or other exogenous shocks may affect RER.

1.3 Anticipated Benefits

The main contribution of this study is to provide a holistic framework that can help understand the interrelationships between transportation accessibility and RER to economic shocks. In practical terms, the proposed framework will be reflected in an index that could be incorporated into the decision-making process of transportation project investments in Indiana.

Additionally, the proposed index can enhance INDOT's transportation decision-making and can be also used as means of communication among the different stakeholders such as elected officials and general public. The spreadsheet tool can be used to perform what-if scenario analyses by estimating the potential effects of improvements in the transportation network to the RER of Indiana. Further, the results of the tool could be included as a complement of other project assessment processes such as multi-criteria analysis and benefit cost analysis. Moreover, it could also be used in activities of the Highway Research and Development program of the FAST Act such as "activities to strengthen transportation planning and environmental decision-making" and "activities to reduce congestion, improve highway operations, and enhance freight productivity" (FHWA, 2015, p. 36).

1.4 Organization of the Report

Chapter 2 provides an overview of the term "economic resilience (ER) and regional ER" and explains how this concept has been formalized and measured in this study. Chapter 2 also defines the regional characteristics associated with RER and how they can be measured through proxy variables. Chapter 3 presents a two-step approach examining whether regional resilience to economic shocks is associated with transportation infrastructure. The first step is based on an expert opinion survey, where questions about the interdependency across regional economic characteristics were asked. The second step is based on a structural equation model (SEM), where the association between the components of resilience and the indicators of RER was assessed. Chapter 4 presents the tool development framework and describes the tool's modules as well as their functionality and purpose. Lastly, Chapter 5 presents a hypothetical use case to illustrate how the tool's outputs can be incorporated in project decision-making in Indiana and outlines the study conclusions.

2. LITERATURE REVIEW AND BACKGROUND

2.1 Concept of Economic Resilience (ER)

According to the Merriam-Webster dictionary, the first known use of the term "resilience" was in 1807 while the first use of the term "resilient" was in 1674. The same dictionary defines resilience as the "[capability] of withstanding shock without permanent deformation or rupture." Research associated with "resilience" could be traced back for many decades in the fields of physics and psychology. The explicit definition of the notion of resilience in physiology dates back to the 1970's (Vernon, 2004). This definition was associated with successful adaptation of children to adverse events and the development of psychopathologies (Reich et al., 2010).

On the other hand, the definitions of resilience could be traced back to studies in the field of Ecology with the work of Holling (1973) and Pimm (1984). Holing states that the behavior of ecological systems could be defined by two properties. First, resilience, that is associated with the persistence of relationships (i.e., functionality) within the system. Second, stability, which is associated the capacity of a system to return to an equilibrium state after a temporary disturbance occurs. Pimm (1984) defined resilience as "how fast the variables return toward their equilibrium following a perturbation." He defined a system as stable "if and only if the variables all return to the initial equilibrium […]" (Pimm, 1984, p. 322). Pimm's definition of resilience was later denominated as "engineering resilience" by Holling in 1996 (Folke et al., 2010) to differentiate it from the term "ecological resilience" (Walker et al., 2004, as cited in Gunderson et al., 2012). More recently, in order to incorporate the role of human actions as an integral part of the systems (i.e., not as an external agent), the term social-ecological resilience was coined. Social-ecological resilience considers people and nature as interdependent (or coupled) systems (Folke et al., 2010), and include the notion of adaptability and transformability as key ingredients or parts of resilience.

2.2 Paradigms of Economic Resilience

Most of the research on ER can be grouped under three main paradigms (Boschma, 2015). These are: the single equilibrium resilience (engineering resilience), multi-equilibrium resilience (ecological resilience), and the social-ecological resilience (adaptive or evolutionary resilience) (Boschma, 2015; Pendall et al., 2010). Social-ecological systems embed concepts of complex adaptive systems or what is also called evolutionary paradigm. In that paradigm, the role of humans, particularly in adapting to new situations, is considered. Pendall et al. (2010) presented a taxonomy of the study of resilience where different study efforts can be grouped based on the nature of shock (i.e., challenge or time dimension) and the resilience lens used. An adapted version of this taxonomy is shown in Table 2.1. Note that under social-ecological resilience, no explicit equilibrium is defined.

2.3 Previous Studies on Economic Resilience

The following section aims to provide an overview of the methods and measurements of RER that are of interest to the scope of this report. In that view, it does not intend to discuss macro or micro economic models from the literature of ER.

Han and Goetz (2015) studied the changes in employment of U.S. counties during the Great Recession by adopting the notion of absorption and recovery from economic shocks. Those authors developed a drop index and a rebound index using employment and calculate resilience as the sum of drop and rebound indices. Han and Goetz (2015) found that each county responded differently to the shock, not only in terms of magnitude, but also in terms of the time when the region was mostly affected. A similar study by Faggian et al. (2018) developed a multinomial model where four categories of regions were created. These categories were based on the "resistance" and "recovery" capacity of each region. The resistance capacity describes the employment change during Italy's recession in the region relative to the national change before and during the recession. The recovery capacity represents the change in employment after the recession. Each region represented a Local Labor Systems (LLS) in Italy. That study found that industrial vocation, population, tourism, and location in districts focused on food and textile sectors were relevant in determining the resilience of regions. They also found that medium-size regions were more likely to simultaneously be more resistant and able to recover faster.

Fingleton et al. (2012) examined the resilience of 12 U.K. regions to four recessionary shocks focusing on both the engineering and ecological resilience. That study compared "engineering and plucking" with "ecological and hysteresis." In the former, the economic shocks have a temporal effect on the long run economic or employment growth. After this period, the previous path of growth is resumed (i.e., rebound to a previous equilibrium). In the latter, a disturbance permanently affects the path of the economy in a region (i.e., memory of the disturbance) (Martin et al., 2016). These authors used restricted and unrestricted seemingly unrelated regressions models for engineering resilience and a vector error-correction model specification for ecological resilience. They found that U.K. regions are different mostly in the magnitude of the initial disruption because of the economic shock, while they did not differ much in their speed of recovery. Similarly, they found that shocks typically have permanent effects on the employment of a region and its neighboring regions.

Jung (2015) studied the impacts of entrepreneurship on ER using a panel and quasi-experimental analyses with the aim to provide evidence of the important factors in ER and show evidence of causality between entrepreneurship and resilience. They analyzed the period between 2000 and 2012 and focused on the 2007 recession as well as Hurricanes Katrina and Rita. The indicator of resilience in that study was based on annual growth rates of income per capita, employment, and population. Their explanatory variables included number of employees, capital stock, human capital, patents, industrial diversity, migration, firm density, federal funding, most affected region dummies, and federal assistant programs. That study found that entrepreneurship positively affects economic recovery of recessions in terms of population and employment growth. A similar trend was found for agglomeration, industrial diversity, patents, physical capital stock, and federal funding. However, employment resilience was negatively associated with per capita income growth. Similarly, the density of firms was negatively associated with employment. This was explained by the possibility that excessive competition in crowded markets can affect the rate of employment growth.

Davies (2011) studied the RER in European regions using unemployment rates as an indicator of regional resilience. That study used indicators of economic strength and fragility (such as GDP per capita), a measure of labor market functioning based on unemployment rate in 2007, and an indicator of agglomeration based on population density in 2005. That author used a linear regression model to investigate how these variables and resilience were associated. That study found that the correlations between economic strength and resilience varied across countries and that manufacturing regions were less resilient.

Kreston and Wojcik (2013) investigated the resilience of metropolitan areas in the U.S. and found that for the recession period, the size, specialization, and high density of subprime mortgages had harmful effects on metropolitan resilience. On the other hand, financial concentration and income demonstrated positive effects. More recently, Angulo et al. (2018) went one step further and examined how the economic structure of Spanish provinces changed (or adapted) after the 2008 economic shock, using two shift-share analyses for four industries (service, construction, industry, and agriculture). Using data between 2001 and 2015, they found that the Spanish provinces with sectorial and locational advantages before the shock or advantages in location after the shock have better performance (i.e., lower drop in employment growth). They also found that areas that specialized in service industries (based on location quotients) were likely to have better performance. On the other hand, the opposite was found for areas that specialized in the construction industry. Other relevant studies include Brown and Greenbaum (2017), who investigated industrial diversity in regional resilience using unemployment as an indicator and Courvisanos et al. (2016), who studied the adaptive capacity of Australian regions.

While these studies provided insightful results on the economic behavior of the different regions under study, they did not consider specific transportation-related factors or broad regional characteristics (e.g., livability); both of these factors could have contributed to their regional performance during or after the economic shock. Moreover, some studies only looked at the economic behavior of the indicator. For instance, in Han and Goetz (2015), no additional information from the counties was considered to explain which variables or characteristics could be associated with the gaps in time and space found for the resilience index. Also, some of these studies (Han & Goetz, 2015; Faggian et al., 2018; Davies, 2011; Kreston & Wojcik, 2013) did not consider the spatial interaction or spillover effects between regions. On the other hand, the work of Fingleton et al. (2012) and Angulo et al. (2018) considered the time dimension and interregional employment linkages; however, other variables that are relevant to regional resilience (such as those outlined in Renschler et al., 2010), were not considered. Finally, none of these studies considered variables that describe the transportation geography of the studied areas.

2.4 Characterization of Regional Economic Resilience

The multi-dimensionality of RER is identifiable due to the different frameworks and wide heterogeneity in responses that could be found from different regions and industries. Although different authors proposed different components of resilience with diverse names, the common underlying principles such as resistance, recovery, and transformation can be found. Some authors explicitly differentiate across the time dimensions of resilience.

The most widely used representation of resilience is based on the “resilience triangle,” (see Figure 2.1) in which the y-axis represents the level of “functionality” of the system and the x-axis represents the time before and after the disruption. With this type of event-driven measure of resilience, the y-axis (functionality) could represent employment levels (Han & Goetz, 2015), number of trips (Cox et al., 2011), or economic output (Vugrin et al., 2010), among others. Typically, resilience is a measure of the relationship between the system’s functionality after the shock and the potential worst-case scenario (i.e., no resilience in the system). Similarly, Rose (2007) presents a framework where the robustness (i.e., static resilience) is defined as the ratio of the “avoided drop” of the system to the worst possible drop. Further, the recovery capacity (dynamic resilience) is calculated by comparing the system output with and without recovery efforts for different time periods or “time steps.” The recovery period is the sum of this difference in all periods or steps (Vugrin et al., 2010).

For robustness capacity, Rose (2007) defines a measurement of direct static resilience and one of total static resilience. The former applies to firms or industries and is referred to as economic “partial equilibrium” analysis. The latter deals with macroeconomic analysis which includes all prices and quantity interactions and its analysis forms part of the economic “general equilibrium analysis.” In this framework, the robustness capacity is measured by comparing the expected performance under disruption with the worst-case scenario in case any resilience is present (i.e., total loss capacity). In

TABLE 2.1
Economic Resilience Approaches (Adapted from Folke, 2006 and Pendall et al., 2010.)

		Paradigms		
		"Engineering" or single-equilibrium resilience	**"Ecological" or multiple-equilibria resilience**	**Social-ecological resilience and complex adaptive systems[1]**
	Focus On:	Recovery and constancy	Persistence and robustness	Adaptive capacity transformability, learning, innovation
Time Dimension ("*When?*")	Short term	Return to pre-condition (e.g., return to previous unemployment rates after a shock)	Establishment of a new pre-condition (equilibria) (e.g., change in growth rates after a given shock)	Continual adaptation (e.g., keep positive or neutral performance despite the shocks)
	Long term	Stability of natural norms (e.g., low unemployment rates in the long term)	Performance improvement (e.g., new employment levels or rates every period)	Continual adaptation (e.g., establishment of new growth paths based on new sectors/ subsectors)

[1]While approaches related to complex adaptive systems can be seen both in the ecological and social-ecological paradigms, this study places it under the third paradigm only.

Figure 2.1, this percentage avoidance of the worst-case scenario is defined by B divided by A or by (A-B)/A. Similarly, the dynamic resilience is defined as the difference between the lines C and D, which represent the level of economic activity with and without hastened recovery (Rose, 2007; Vugrin et al., 2010). This could be also represented as continued trigonometric, linear, or exponential functions (Cimellaro et al., 2010).

Another study using this approach is Han and Goetz (2015). Those authors provided a resilience index based on an employment time series that are used to identify the peak and trough points that mark the "Drop" (robustness) and the "Rebound" (recovery) of the economy, respectively. Drop is the decline in employment until the valley point is reached, and the rebound is the rate of recovery in employment after the lowest point has been reached.

In addition to the resilience triangle (see Figure 2.1), Francis and Bekera (as cited in Bond et al., 2017) presented an approach in which the absorptive, adaptive, and recovery components are taken into consideration explicitly. Francis and Bekera improve the Norris et al. (2008) framework by incorporating stakeholders' engagement and the setting of resilience objectives as part of their framework (Bond et al., 2017).

Other authors present frameworks where input-output (I/O) tables or general equilibrium models (GEM) are used. For instance, Martinelli et al., (2014) present a model considering the economic effects and characteristics that could be used to predict the impacts of natural disasters in monetary terms. That model emphasizes the economic interdependencies that exists between industries and lifelines. The authors present a modified version of the HAZUS model from Federal Emergency Management Agency (FEMA). Martinelli et al. (2014) compute the direct losses from the disaster, considering buildings and lifelines. The indirect losses are calculated using a GEM (instead of I/O tables) and then a reliability index is calculated. Similarly, Rose and Liao (2005) presented a computable general equilibrium approach (CGE) in which the CGE models were adapted to account for the effects of major disruptions of critical inputs and then applied the framework to a case study for the evaluation of the economic impacts of a hypothetical disruption to the water system in the Portland metropolitan area. The authors highlight that the main advantage of using a CGE model over other economic models is that it allows input substitutions as in the real world. Nevertheless, the level of complexity in using this type of model is still a limiting factor.

In addition to these studies, some frameworks were developed with the intention of incorporating resilience into the project decision-making process. The RAND Corporation (Bond et al., 2017) presented a resilience framework, in which the "resilience dividend" is quantified in terms of an economic value. The resilience dividend is the difference between the resilient-built scenario and an alternative scenario for the project such as a do-nothing or business as usual scenario. The quantification of the resilience dividend includes not only the benefits of risk reduction, but also the co-benefits that improve the current condition of the project and the quality of life of people. Those authors pointed out the importance of adequately measuring these benefits. That study stated that, when analyzing and comparing a levee project with a land use planning project, the benefits of both might be similar. However, the land use project could bring additional externalities such as air quality, recreational areas, and other important effects. The non-quantification of these externalities could bring a bias towards the implementation of levees. FHWA (2018) synthetizes studies and lessons learned in FHWA studies related to climate change and extreme weather events in order to guide their incorporation as part of the project development process. The economic analysis quantifies the costs and benefits of different adaptation scenarios. The analysis considers the costs of damage repair, economic losses to local businesses, and socio-economic costs due to extreme weather events and climate change. Both frameworks, however, have the issue of non-quantifiable benefits and data availability for other variables that are quantifiable.

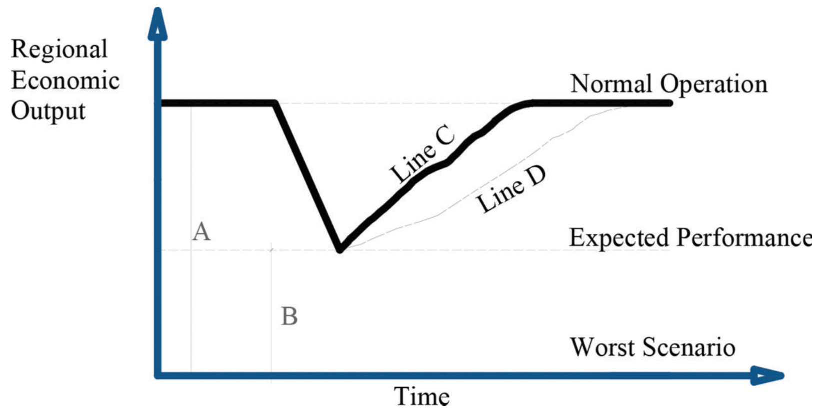

Figure 2.1 Triangle of resilience. (Adapted from Rose, 2007 and Vugrin et al., 2010.)

2.5 Developing a Metric of Regional Economic Resilience

Based on the literature review of previous studies of resilience and the metrics used to characterize resilience, a metric of RER was developed in order to reflect the long-term influence of transportation on RER and reflect the local regional capacity of each region under study. This economic indicator is obtained through a shift share analysis based on annual employment data at the county level covering the period before and after the recession. The regional performance is calculated annually and aggregated in a process called dynamic shift-share analysis. This metric is based on the "local competitiveness" of each region. The resulting index reflect the resistance and recovery capacity of regions depending on the period under analysis. The period measured by the 2000 decennial census reflects the resistant capacity of the region(s) while the period measured by the 2016 ACS reflects the recovery capacity. Thus, the period of study includes two recessions, the 8-month recession in 2001 caused by Y2K scares, and the more recent 2007–2009 subprime mortgage-driven Great Recession. While these time periods are fixed for all regions, it should be noted that the recession followed different time periods for different counties in Indiana.

Following the adopted definition of resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedback" (Walker et al., 2004, p. 6), the indicator of RER considers the regional performance during two periods. First, it considers the period during the recession, where a region could be categorized as resistant if the regional performance is positive. A positive regional performance indicates either that the region did not decrease in its total employment or that it decreased at a lower rate than the expected national-industry mix trends. In other words, a region with decline in employment during the recession would be resistant if the regional competitiveness decreased the negative trend effect of the recession. Second, during the rebound or recovery period, the regional performance will indicate if the recovery is the result of national- or industry-related trends or due to the regional competitiveness.

2.6 Components of Regional Economic Resilience

The literature points out a set of urban or regional characteristics that are associated with regions' capacity to resist or recover from recessionary shocks. These different characteristics are presented as a group of "components" that, in conjunction, contribute to building the RER capacity of regions. This section presents a summary of those components that were derived from Renschler et al. (2010), Chapple and Lester, (2010), Jackson et al. (2015), Briguglio et al., (2009), and Ekogen et al. (2009). The resulting set of theoretical components is presented in Figure 2.2.

Although the components of resilience are shown as independent in Figure 2.2, they could be significantly interrelated with each other. In addition, each component is represented by a subset of indicators that aim to characterize each component. Studies focused on general resilience and disaster-related resilience present comprehensive lists of indicators (see for example Renschler et al., 2010; and Rockefeller Foundation & ARUP, 2015). Note that the focus of this study is on indicators of accessibility and transportation. The following sections describe these components as well as the main indicators chosen to represent them.

2.6.1 Human Capital

Human capital embodies the knowledge, skills, and competencies of individuals that contribute to the creation of economic well-being (Healy & Côté, 2001). In that vein, higher levels of human capital are associated with higher levels of regional performance. Human capital is typically measured by indicators based on education and/or share of managerial and engineering occupations in a given region. Education not only brings technological innovations, but also builds up a workforce capable of completing complex tasks. Wojan, (2014) provides empirical evidence of the association between resilience and human capital by examining creative counties (as defined by a share of

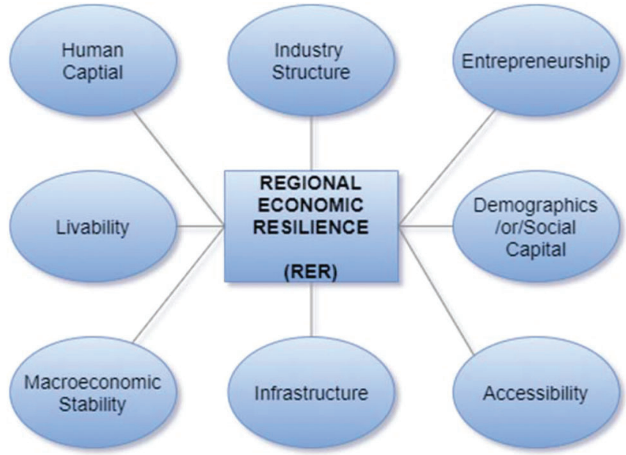

Figure 2.2 Components of regional economic resilience.

more than 25% in creative occupations that, according to Wojan's definition, included artists) during the 2007 recession. That study found that creative counties were more likely to be classified as resilient as they gained employment after losing them during the recession. Among them, the metropolitan creative counties had the higher share; nonetheless, there were also non-metropolitan counties that continued to grow in employment both during and after the recession.

2.6.2 Industrial Diversity

The role of industrial diversity during economic recessions is widely recognized in the literature by scholars and practitioners. In other words, diversity in industries should allow for more resilient behaviors. This relationship is usually explored using unemployment rates and diversity indicators (such as Herfindahl-Hirschman index (HHI)). The findings usually show an inverse relationship between unemployment rates and industrial diversity (Watson & Deller, 2017). For example, Izraeli and Murphy, (2003) found strong links between industrial diversity and unemployment rates in 17 U.S. states using data between 1960–1987 and 1988–1997, whereas Simon, (1988) found a similar trend at the MSA level. Simon and Nardinelli, (1992) argue that this relationship is due to the "portfolio effect," in which an employee that has been laid off in a declining industry has a higher probability of finding another position in another expanding industry. In addition, Kreston and Wojcik (2013), while researching the effect of the Great Recession on U.S. metropolitan areas, found a negative association between resilience and industry size and specialization. However, caution should be exercised when considering specialization as the opposite of diversification. Duranton and Puga, (2000) argue that there is a need for both "large and diversified" cities as well as "small and specialized" cities. This, nevertheless, creates a dichotomy of responses under shocks in the sectors of specialization and at the regional level, making the study of their responses more difficult. The primary indicator for industry specialization used is the location quotient (LQ).

2.6.3 Entrepreneurship

Entrepreneurship aims to reflect the capacity and opportunities for innovation that a region can offer for workers and firms, which are assumed to have a positive association with resilience. Entrepreneurship combines existing factors of production (such as labor) in innovative ways that foster productivity (Koster, 2016) and economic growth. Therefore, while the components are assumed to be independent, in practice this component could be highly correlated with human capital. Jung (2015) specifically studied the association and causality between regional resilience to hurricanes and economic shocks and entrepreneurship in the U.S. Gulf coast region. That study showed that employment and population growth were positively linked to entrepreneurship. Similarly, Fairlie, (2013) studied entrepreneurship based on the rate of business ownership obtained from matched time series data from current U.S. population surveys in 1996 and 2009. That author found that higher unemployment rates increase the probability of individuals starting businesses. In general, recessionary periods seem to boost entrepreneurship by individuals who are willing to accept higher risks of ventures as an alternative to unemployment. In the same vein, there is evidence that research and development of existing firms follows a pro-cyclical behavior (Koellinger & Thurik, 2012). Nonetheless, as entrepreneurship is a function of how individuals and firms recognize opportunities and possess the motivation, skills, and capacity to explore them (Cabrita et al., 2015); it is a factor difficult to measure in practice.

2.6.4 Livability

The component of livability aims to reflect the quality of life that each place can offer. FHWA (FHWA, 2018) ties this concept to the level of access to broader opportunities, such as good jobs, affordable housing, quality of schools, and safer streets and roads. Similarly, the American Association of Retired Persons (AARP, n.d.) developed an index based on seven different components of livability, including safe and convenient transportation. In general, it is assumed that livable communities (e.g., communities with high-quality amenities) attract creative class workers and firms (Florida, 2002) that reinforce a region's human capital and entrepreneurship, as well as providing opportunities to foster social capital. Evidence from this association was found by Glaeser and Gottlieb, (2006) while studying the "urban renaissance" phenomenon in the U.S. Those authors found an association between amenities and high-income people. Similarly, Florida (2002) argues that a concentration of "Bohemians" (occupations covering authors; designers, musicians and composers; actors and directors; craft-artists, painters, sculptors, and artist printmakers;

photographers, dancers; and artists, performers, and related workers) in a region will attract talented individuals. These individuals are expected to have a positive role during recessionary shocks. Lastly, Wojan (2014) highlights the positive role of the creative class during recessions and that these types of workers tend to locate in areas with a high number of amenities. However, that author also noted that this association was stronger during the pre-recession period during 1990s than during or after the recession period.

2.6.5 Macroeconomic Conditions

The macroeconomic conditions component aims to capture the economic performance of a region prior to the recession. Recessionary periods could accelerate or exacerbate socio-economic issues that already exist in a region. It is known that recessions tend to disproportionately affect minorities (such as African-Americans and Hispanics) and adults with few skills and limited education (Seefeldt et al., 2013). The situation was even worse during the Great Recession, because it also hit middle- and high-income groups, which caused charitable programs for low-income people to be curtailed. This, in turn, deepened the recession's effects on low income people (Seefeldt et al., 2013). The macroeconomic component also aims to capture differences in regions' performance because of other characteristics, such as tax climate. Tax policies could affect the ability of a firm to retain workers during the hardship of recessions and encourage new investment during the aftermath of recessions (Hicks & Kuhlman, 2011). In this study, it is hypothesized that economies with high vitality prior to the recession will have better performance during recessionary periods. The component of macroeconomic conditions is represented by unemployment, poverty rates before the recession, and average regional performance between two periods of analysis. Additional aspects include the presence of unions in the labor market and "right to work" policies. The states with unions appeared to have fared better during the recession but also took longer to recover in the post-recession period.

2.6.6 Social Capital

This dimension refers to social networks, norms and sanctions that facilitate cooperation among individuals and communities (Halpern, 2005). The term became popular with Putnam's publication "Bowling Alone" (Healy & Côté, 2001), and nowadays, there are various studies that provide evidence of the positive role that social capital has on economic well-being (Partridge et al., 2008). One of the traditional notions of social capital is that it influences the economic performance of regions through the reduction of transactions costs; norms and sanctions ensure that business arrangements and trade exchanges are made based on tacit trust. For example, the need to take care of a business reputation within a group eliminates the need for detailed contractual documents (Halpern, 2005). Social capital provides the glue that facilitates co-operation, exchange, and innovation (The New Economy: Beyond the Hype as cited by (Keeley, 2007). Similarly, it provides networking for job opportunities that could ultimately influence the economy of a region (Keeley, 2007).

Social capital has three dimensions (functions or characters in Halpern, 2005). The first, bonding, refers to intimate ties within families, close friends or associates, people who share culture and ethnicity or a common identity. The second, bridging, goes beyond identity to include associates, peers, and distant friends. The third dimension, linking, refers to the links outside an individual's circles. These are vertical links that reflect the access to outside resources and ideas that could be used to support and guide local initiatives (Partridge et al., 2008).

2.6.7 Infrastructure and Transportation Accessibility

The components of infrastructure, services, and transportation accessibility aim to capture the availability of development supporting infrastructure and access to services. Infrastructure include roadways, railways, and ports in each region among others. The influence of this dimension on regional economic performance is discussed in more detail in the forthcoming sections. This component also aims to reflect the level of accessibility to populations since it is expected that agglomerated and urbanization economies reduce the effects of recessions by allowing mobility of workers. During recessions, firms or workers could try to relocate to areas with large markets, suppliers, and labor (Quigley, 1998, as cited by Kreston & Wojcik, 2013).

The role of transportation on RER is not as explicit as it is in the event of sudden natural or man-made disturbances. Some literature, however, has identified transportation, as one of the important assets supporting regional advantages that drive both regions' economic development and regions' capacity to resist recessions (see Ekogen et al., 2009; Jackson et al., 2015). Notwithstanding that evidence, the multi-dimensionality of ER (i.e., differences in time, space, geography, and factors affecting it) brings a level of complexity that makes the study of the role of transportation cumbersome. Consequently, there is an incomplete understanding of how transportation infrastructure may affect the ER of regions.

The incorporation of transportation in the study of resilience will be dependent on the paradigm of resilience used as well as the type of shock under consideration (i.e., the "*of-what*" and "*to-what*" dimensions of resilience). Under the assumption that the physical capacity of regions is essential for maintaining a competitive advantage (Jackson et al., 2015), the notion of social-ecological systems, which considers the social and economic interactions between communities and regions, could be used to describe the role of transportation infrastructure on the long term capacity of regions to resists recessions.

Although the contribution of transportation to the economic growth of a region has received significant attention, its role during periods of economic downturns has not been widely examined. As shown in the preceding sections, the study of ER presents indices and econometric models that provide insightful results on the economic behavior of the different regions; however, most past studies have not examined or delineated which transportation factors or regional characteristics contribute to the regional performance during or after an economic shock. (Jackson et al., 2015) presented a transportation component ("dimension" in the original article) that is composed of railroads and airports. That study also included a factor of scale and proximity that considers the average commuting time. Another study conducted in the U.K. (Ekogen et al., 2009) considered a component called "assets and infrastructure," which includes rail connectivity and proximity to international airports. In addition, Östh et al. (2015) evaluated an adapted version of the resilience capacity index (RCI) and its relationship to a measure of accessibility to jobs. The authors concluded that ER and accessibility are correlated in a nonlinear fashion.

Finally, as part of the econometric models presented in the proceeding sections, many of those studies pointed out the association between specialization and diversification of industries and the resilient response of regions. More specifically, the association of diversity of industries and resistant capacity to shocks appears to be strong. Likewise, the association between industrial specialization and the rebound capacity of regions is also strong. As for transportation linkages between regions, there is a trend towards specialization in industries for which the region has a competitive advantage (Taaffe et al., 1996); therefore, a dichotomous role of transportation on regional performance could be hypothesized.

3. DATA AND METHODS

3.1 Overview

The relationship between transportation accessibility and Regional Economic Resilience (RER) was analyzed in different steps. Figure 3.1 describes the different steps that were undertaken. First, an opinion survey was collected from transportation experts in Indiana. After the survey was collected, an Analytical Hierarchy Process (AHP) was used to identify possible relationships among the components mentioned in Section 2.6. The AHP was performed using the input from the experts' opinion survey. Once the relationship among the components was defined, the components that resulted to strongly influence RER were modeled using structural equation models (SEM). For that last step, data that described each component was gathered from different public and proprietary sources. The final model was used as an input for the RER tool, where it helped to inform the robust, recovery and built scenarios. Finally, the resilience index scores for each county are a weighted average based on results from the experts' opinion survey and SEM results.

3.2 Soliciting Experts' Opinions

A questionnaire was designed in an attempt to collect information from experts about RER and interdependencies within and among the aforementioned components. The two main objectives of soliciting experts' opinions were to understand if the stakeholders were aware of the concept of RER in the context of the last economic recession and to identify the direction and magnitude of influence across the different components of RER prior to the last recession. The questionnaire (survey instrument) was designed in Qualtrics by the Purdue research team and was approved by the Institutional Review Board (IRB) at Purdue University (IRB protocol #1803020346).

3.2.1 Pilot Instrument

The pilot instrument was examined in terms of the accuracy of the instructions for each question and provided better information on whether the designed instrument could effectively accomplish the study objectives. The sample for the pilot survey consisted of 25 students from a relevant transportation graduate class at Purdue University. The pilot survey was conducted between February 9 and 14, 2018. The results of the pilot survey allowed the researchers to evaluate and refine the method used for the analysis.

3.2.2 Final Instrument

The final questionnaire began with an introduction about the purpose of the study and important information for the participant, such as confidentiality, length of the survey, and contact information for the research team in case of further questions. The survey was divided into three sections. The first section collected data on respondents' basic information, including the type of organization they work for, their role in the decision-making process for transportation projects in that organization, and the years of work experience that they have. The second section asked about each respondent's familiarity with the concept of "RER." The third section contained nine questions aimed at understanding the respondent's opinions on the magnitude of influences across the different components of RER. These components included *human capital, industrial diversity, entrepreneurship, livability, social capital, macroeconomic conditions, accessibility to labor and markets, and infrastructure (energy, health, and transportation)*. A blank space was also provided for respondents to fill in up to two additional factors not listed within the survey. The first question in the third section asked to what extent each of those components affect RER. The next eight questions asked experts' opinion to what extent each component influences the others. Data collection started on March 22, 2018 and ended on May 16, 2018. The survey was distributed via email to INDOT, MPOs, Rural Planning

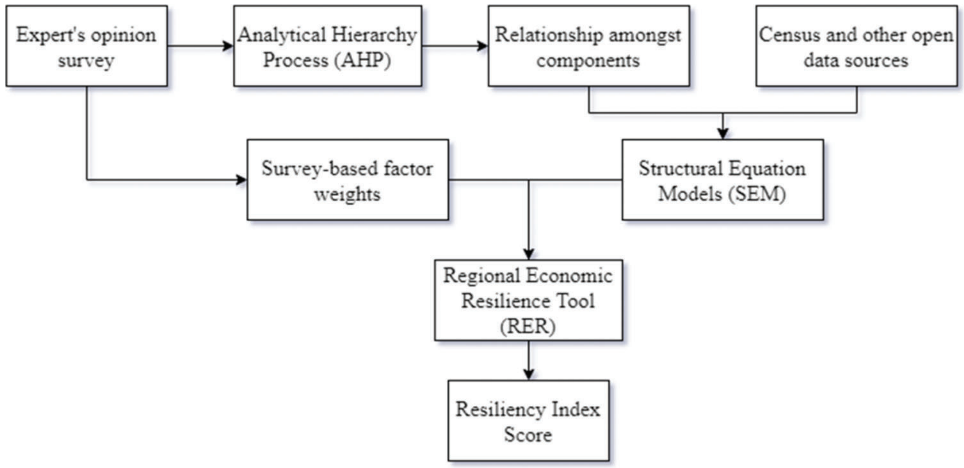

Figure 3.1 Process to identify the relationship between transportation and RER.

Organizations (RPOs), Indiana Association of Regional Councils (IARC), CONEXUS, Purdue Center for Regional Development (PCRD), and other transportation consultancies. The survey was distributed to 53 representatives of these organizations, with a 66% response rate (35 responses). From the 35 responses, only the 25 fully completed responses and were used in the data analysis. The expert opinion results are presented in the following sections. The final survey questionnaire is attached in Appendix A.

3.2.3 Expert Opinion Results

3.2.3.1 Section 1: Respondents' profile. Out of the 25 valid responses, 8 of the respondents worked for MPOs, the most represented entity in the survey (Figure 3.2). Additionally, the survey was completed by 6 representatives from INDOT and 4 individuals working for RPOs. Those that classified themselves as "other" stated that they worked in other governmental entities.

The main role of respondents is advisory role (11 responses), followed by decision-makers. Four respondents chose the "other" option and stated that they perform both roles or were the only staff in those organizations (Figure 3.3).

The final question in section one asked about years of work experience. Out of 24 respondents that answered this question, 15 stated that they have worked for thirteen or more years in the transportation field. This finding provides confidence in the opinions of the respondents, as this survey was intended to be answered by experts in the transportation sector (Figure 3.4).

3.2.3.2 Section 2: Familiarity with the RER concept. This section explored the familiarity of respondents with the concept of RER (Figure 3.5). Of the 24 respondents that answered this question, 12 stated that they have heard of the concept, but they do not use it regularly. Only 3 respondents stated that they have not heard of RER.

Of the different organizations represented in this survey, MPO representatives stated that they are familiar with the concept of RER but do not use it regularly (Figure 3.6). Additionally, most of respondents from INDOT stated that they have heard of RER but they have not used it. The ones that use it regularly are representatives from private consultancy firms.

3.2.3.3 Section 3: Magnitude of influence of different components on RER. Of the components considered in the survey, respondents stated which ones most strongly, or very strongly, influenced RER (Figure 3.7). No respondent indicated that the components did not have any influence on RER. *Livability, social capital, and macroeconomic conditions* were considered by some respondents as having little influence on RER. Among the other components, respondents answered that ethnic/racial diversity, education/training, and strategic plan for economic development were strong or very strong factors affecting RER.

3.3 Modeling Interdependencies

The interdependencies between the different components of RER are not clearly stated in the literature. Even though social capital is expected to influence *human capital* to some extent, the magnitude and direction of this influence is unknown. To that end, the following section presents two theoretical models used to identify those influences. The first model used an Analytical Hierarchy Process (AHP) to find the magnitude and direction of the interaction and check the consistency of survey responses. The second model applied exploratory factor analysis (EFA) and SEM techniques to test the statistical significance of those interactions.

3.3.1 Preliminary Analysis: Analytical Hierarchy Process (AHP)

Three different techniques were considered to perform the first analysis of the survey. Analytical Hierarchy

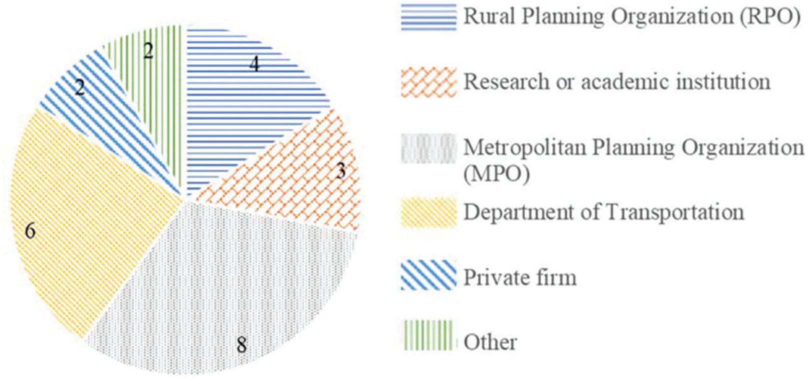

Figure 3.2 Types of organizations where respondents work.

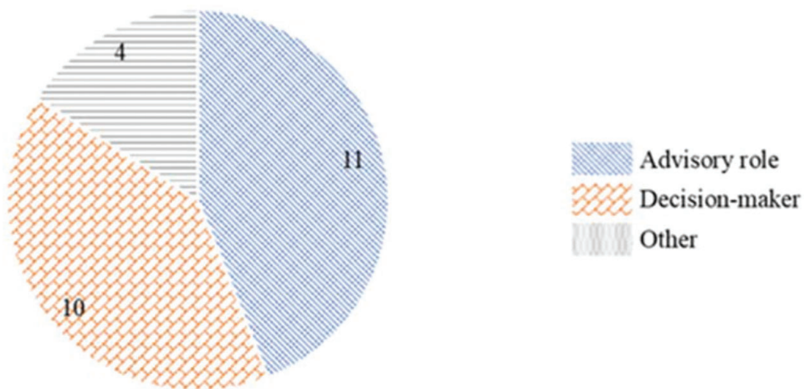

Figure 3.3 Respondents' role in the decision-making process for transportation projects.

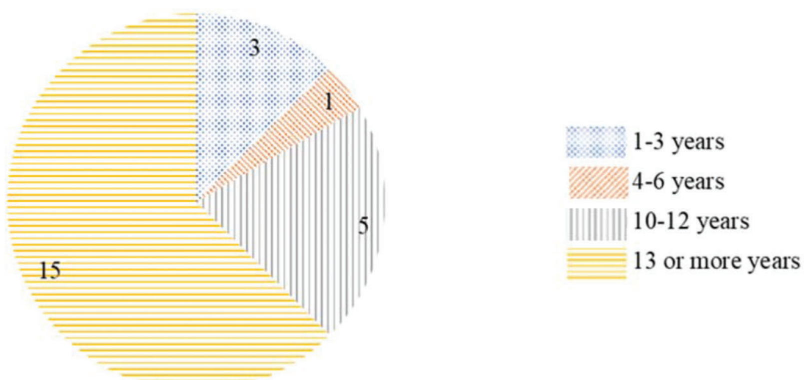

Figure 3.4 Respondents' years of work experience.

Process (AHP), Analytical Network Process (ANP), and Fuzzy Cognitive Maps (FCM). A summary of the strengths, and weaknesses are presented in Table 3.1.

AHP is a procedure for establishing priorities in multi-criteria decision-making problems. Group decision-making is one of its applications used around the world in a variety of decision situations related to government, business, industry, and education. The use of AHP in the context of this project was mainly prioritization, when the relative merit of member of a set of alternatives is determined. This technique is also the best well-known multi-criteria decision-making method. Based on the pair-wise comparisons, the relative significance (weights) of elements of the hierarchy structure are calculated (Tsyganok, 2009). On a similar note, the ANP is a generalization of the AHP; however, the ANP is represented by a network rather than a hierarchy. The ANP comprises of 4 steps: (i) model construction and problem structuring, (ii) pairwise comparisons and priority vectors, (iii) super-matrix formation using a Markov chain process, and (iv) synthesis of the criteria and alternatives' priorities, and selection of the best alternatives (Görener, 2012) Both the AHP and ANP use pairwise comparisons to measure the weights of the components of the structure, which are finally prioritized. Finally, FCMs have been used to model decision-making in

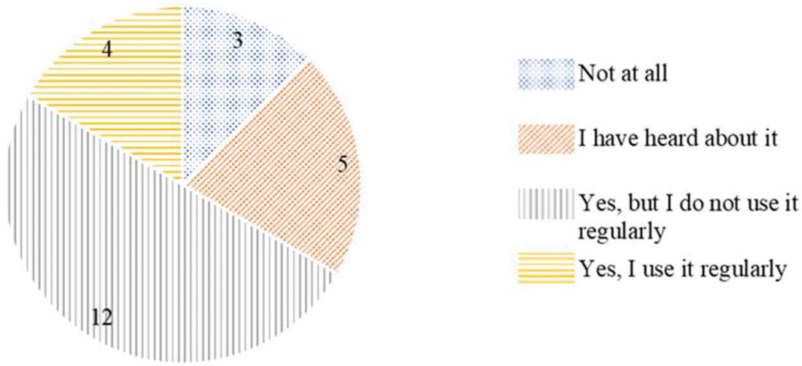

Figure 3.5 Familiarity with the concept of RER.

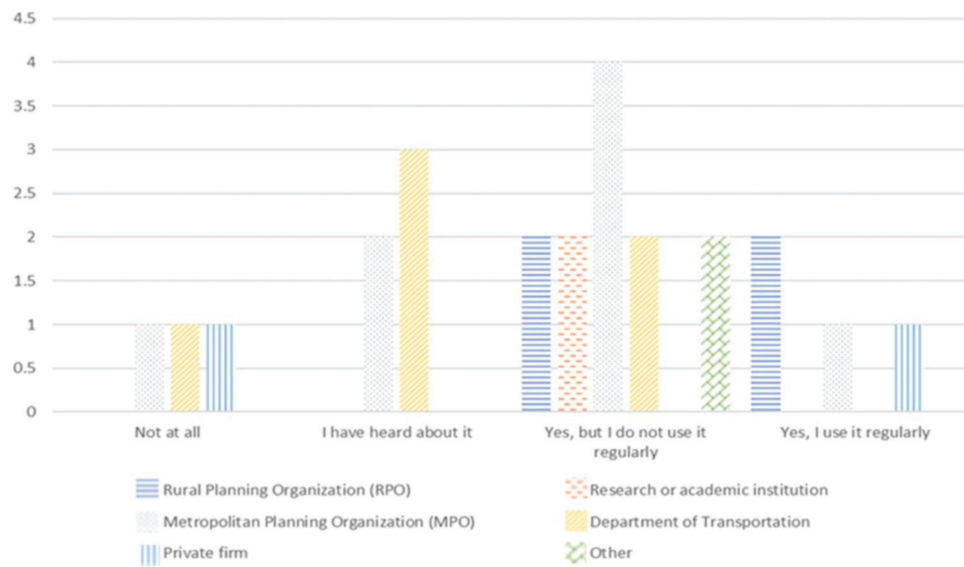

Figure 3.6 Familiarity with the concept of RER among different organizations.

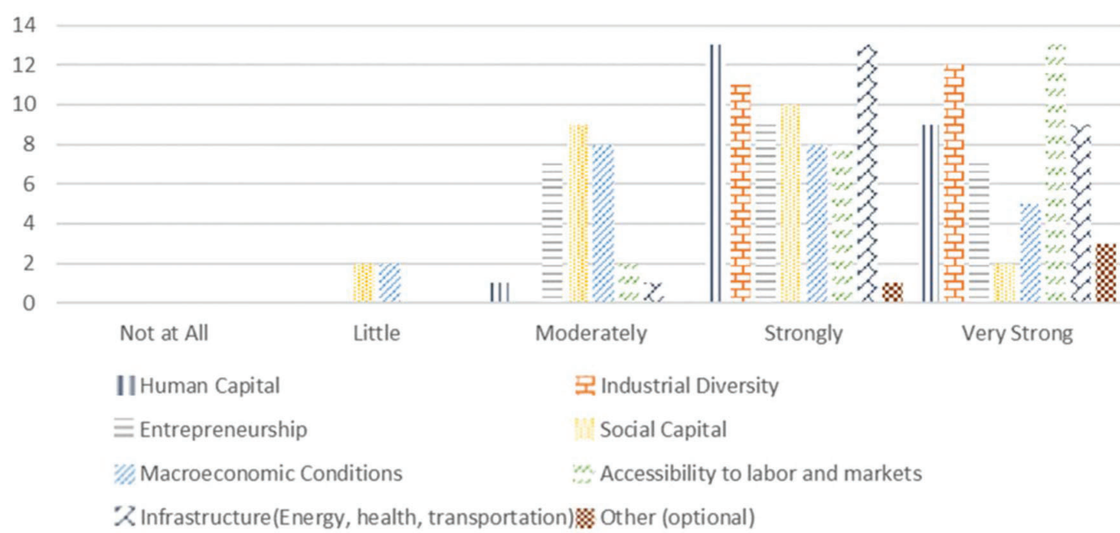

Figure 3.7 Extent to which each of the components affect ER.

social and political systems. That technique is computed by using fuzzy logic. This is typically derived subjectively from the judgments of experts knowledgeable about a topic. As a result, the numerical weights given to edge strengths can vary depending on the expert. (Byung Sung Yoon & Jetter, 2017). In a numerical

TABLE 3.1
Summary of Decision-Making Techniques

	AHP	ANP	FCM
Strengths	• Popular and easy methodology. • Directional hierarchical relationship between the components. • Helpful in setting priorities and making the best decision when both qualitative and quantitative aspects of a decision need to be considered (Begičević et al., 2007).	• Allows for complex relationships among decision levels and attributes (Begičević et al., 2009).	• Positive and negative feedback loops in the cognitive map show that changes in a concept can ultimately lead to still more changes. • The resulting FCM models are generated in interviews, focus groups, or workshops and represent complex and dynamic systems as elements (so-called concepts) and cause-and-effect relationships (Solana-Gutiérrez et al., 2017).
Weaknesses	• Many decision problems cannot be structured hierarchically because they involved iteration of higher-level elements in a hierarchy on lower level elements. • Comparison of results shows that there are significant. differences between AHP and ANP outcome derived from interdependencies, outer dependencies and feedbacks (Görener, 2012).	• Less prominent in literature (Görener, 2012). • It requires to develop a lot of pairwise comparison matrices (Lesmes et al., 2009). • It ignores the different effects among clusters (Velasquez & Hester, 2013).	• Assumes symmetrical behavior (Perusich, 1996). • Difficult to develop because it requires numerous simulations (Velasquez & Hester, 2013).

analysis, the concepts are represented by a state vector and the relations between concepts by a fuzzy relational matrix. This method is often used in collaborative decision-making.

The research team finally decided to use only AHP to find the interactions between the components. Aside from the strengths of this method, it was also chosen because it allows one to check consistency in the survey responses. The steps to perform AHP are as follows:

1. Section 3 of the survey was used to perform this analysis. The average value of the questions, "In your opinion, to what extent does a component influence another component?" was used to create the first matrix.
2. The first matrix was used to create a pairwise comparison matrix. This step is known as computing the vector of criteria weights.
3. A matrix of option scores was computed from the comparison matrix. This is also known as standardized matrix.
4. Finally, the standardized matrix is checked for consistency based on the computation of the consistency index (CI). A perfectly consistent decision maker would have a CI of 0, but small values of inconsistency are tolerated if:

$$\frac{CI}{RI} < 0.1 \qquad \text{(Eq. 3.1)}$$

where RI is the Random Index, taken from Table 3.2 (Saaty, 1980). The value M represents the number of components evaluated, which in this case is 8.

From the AHP used in this analysis, the RI is 1.41 with a CI of 0.14. Following Equation 3.1, this leads to a value of 0.1 and indicates that the survey responses are consistent. In order to define the interdependencies among the components, a threshold of 1.90 was considered (see Table 3.3). The relationships identified were used in the SEM model.

TABLE 3.2
Values of the Random Index (RI) for Small Problems

M	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

The model suggested by the interdependencies that resulted from the AHP are presented in Figure 3.8.

3.3.2 Structural Equation Models

Structural equation modeling is used to represent relationships among observed variables. This modeling technique aims to provide a quantitative test of a theoretical model based on several research hypotheses. SEM serves to test sets of variables that are defined by constructs and how they interact with each other. In SEM, there are two types of variables: latent variables and measured variables. The latent variables are indirectly measured, and hence are inferred from a set of variables that are measured. The measured variables are used to infer the latent variables. In this study, first, the four identified components were tested in terms of reliability and validity. In particular, the structure of these components was examined using exploratory factor analysis (EFA) to form the measurement model (Golob, 2003). The variables considered for the EFA were drawn from Chacon-Hurtado, (2018). The data were collected mainly from public sources. In order to select the observed variables that best represented each of the latent variables, goodness of fit statistics such as

TABLE 3.3
AHP Results

	Human Capital	Industrial Specialization	Entrepreneurship	Livability	Social Capital	Economic Health	Accessibility	Infrastructure
Human Capital		0.57	**2.00**	0.58	0.47	0.69	0.44	0.53
Industrial Diversity	1.76		0.64	1.65	1.60	1.89	0.43	0.42
Entrepreneurship	0.50	1.57		0.56	0.50	1.61	0.51	0.54
Livability	1.80	0.61	1.80		1.89	0.63	0.69	0.44
Social Capital	1.90	0.63	**2.00**	0.50		1.17	0.71	0.62
Economic Health	1.45	0.53	0.62	1.60	0.86		1.81	**1.95**
Accessibility to Labor and Markets	**2.25**	**2.30**	**1.95**	1.45	1.40	0.55		0.38
Infrastructure (Energy, Health, Transportation)	**1.90**	2.38	1.85	2.29	1.62	0.51	2.60	

Note: **Boldface** indicates components that surpassed the AHP threshold of 1.90 considered for further analysis.

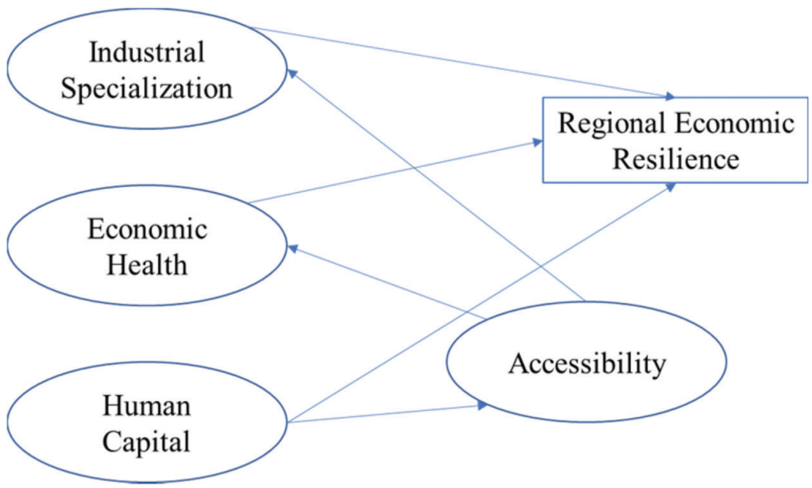

Figure 3.8 Results of AHP.

chi-square, Comparative Fit Index (CFI), Tucker Lewis Index (TLI), Root Mean Square Residual (RMSEA) were considered. After an extensive analysis and considering that the observed variables for each different latent variable are measured in different scales, only three observed variables for each latent variable were measured at the end of the analysis. Those variables allowed convergence of the model and are further explained in the data section.

Next, a structural equation model considering the four identified components and the response variables was estimated. In Figure 3.9, the latent variables are expressed in the form of a structural model. The assumed causal relations are presented as direct paths. Coefficients to be estimated express the strength and sign of the causal paths. SEM is implemented in STATA/SE 15 software, which allows full information maximum likelihood estimates based on covariances between the observed variables. In the estimation, hypothesized latent variables correspond to the theoretical constructs, which in turn are related to the observed variables through the measurement models. Goodness of fit statistics such as chi-square, Comparative Fit Index (CFI), Tucker Lewis Index (TLI), Root Mean Square Residual (RMSEA) ensure adequate model fit.

The SEM proposed to answer the research question is shown in Figure 3.9. The model hypothesizes that *industrial diversity* influences total employment as a proxy for RER directly but also is influenced by *accessibility*. *Economic health* influences RER directly and is also influenced by *accessibility* to a certain extent. Finally, *human capital and entrepreneurship* influence RER directly and are influenced by *accessibility*. The definition of the measurement variables and further discussion on the latent variables are provided in the next section.

3.3.2.1 Data. As the survey results showed, the respondents identified *industrial specialization*, *human capital and entrepreneurship*, *economic health*, and *accessibility* as

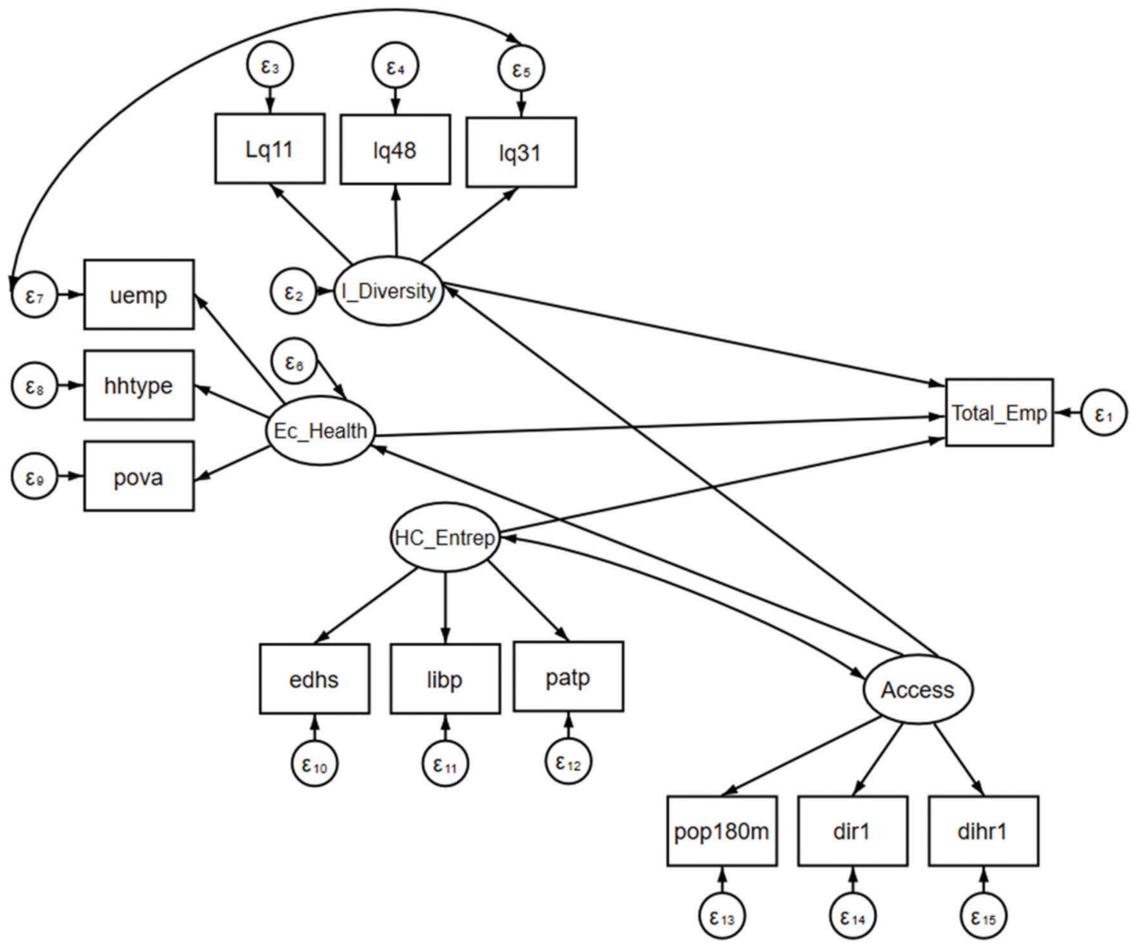

Figure 3.9 Structural equation model.

the most important factors in RER. For that reason, the final model includes the response variable (regional performance) and four latent variables:

- *Industrial specialization* refers to the degree to which the economic base of a region is concentrated in a few or a variety of industry sectors. It usually refers to the share of jobs in each industry sector within a region. It is the inverse of industrial diversity.
- *Economic health* refers to the status of a regional economy. It includes measures of macroeconomic conditions—economic growth, employment, and economic stability.
- *Human capital* refers to the knowledge "stocks" of individuals within a region (e.g., level of education). For the purpose of this model, human capital is also linked with entrepreneurship, which refers to the flexibility and attitude that people possess to innovate and invest in new ideas and start new businesses while assuming all the risks and rewards of the venture.
- *Accessibility* to labor and markets refers to the amount of opportunities (e.g., services, activities, labor force, and customers) that are available for people and firms through the transportation system. It also refers to the amount of transportation infrastructure available within a region.

In order to represent each latent variable considered in the model, data for three observed variables per latent was collected. The response variable is regional performance measured in terms of actual number of jobs and was collected from Emsi (2017). Total employment is a metric used in economic base analysis, which seeks to measure the impact of economic growth and decline in the entire regional economy. Total employment includes base employment (employment in activities in which regional output exceeds regional needs, i.e., export industries) and support employment (employment in activities that are sources of support for the region's economic base industries). Additionally, the total employment captures not only hire for work (paid jobs), but also self-employed and entrepreneurs. The total employment of net commuters (incoming labor force minus outgoing commuters) determines whether an area is an employment center. The total employment variable from Emsi is defined as a "place of work" jobs indicator. A particular job can be performed by a county resident or labor force commuting from outside the county. The observed variables that explain each latent variable are listed in Table 3.4.

Note that, for the purpose of creating the resilience index, models for 2000 and 2016 data were estimated. The years 2011–2016 were selected as the post-recession period for two reasons. First, because the goal was

TABLE 3.4
Description of Variables (2016 values)

Latent Variable	Observed Variable	Mean or Percentage	Standard Deviation	Source
	Total employment[1]	62,708	240,000	(Emsi, 2017)
Industrial Specialization	Location quotient NAICS 11 agriculture, forestry, fishing and hunting annual percentage change	1.95%	—	(Emsi, 2017)
	Location quotient NAICS 48 transportation and warehousing annual percentage change	-11.76%	—	(Emsi, 2017)
	Location quotient NAICS 31, manufacturing annual percentage change	6.15%	—	(Emsi, 2017)
Economic Health	Percentage of household type with single parent	10.63%	—	(U.S. Census Bureau, 2017)
	Percentage of people of all ages in poverty	14.56%	—	(U.S. Census Bureau, 2017)
	Percentage of civilian labor force unemployment rate	6.86%	—	(U.S. Census Bureau, 2017)
Human Capital and Entrepreneurship	Percent high school graduate or higher (population 25 years and over)	37.92%	—	(U. S. Census Bureau, 2017)
	Number of libraries per capita $\times 10{,}000$	0.012	0.008	(Pelczar et al., 2019)
	Total number of patents per capita $\times 10{,}000$	2.145	3.262	(U.S. State Patenting, 2017)
Accessibility	Population within 180-min drive (thousands) from county centroid	19.415	9.096	(U.S. Census Bureau, 2017)
	Distance to the closest rail station class 1 (miles)	21.217	13.871	(Bureau of Transportation Statistics, 2019)
	Distance to interstate (miles)	0.029	0.060	(Bureau of Transportation Statistics, 2019)

[1]Total employment does not account for the size effect. Thus, Marion County, for instance, will have a higher employment base than rural counties.

to analyze the post-recession effects rather than the immediate recovery effects of the recession, it was important that the years chosen did not overlap with the recession itself as well as with the immediate aftermath of said recession. The second reason 2011–2016 was chosen was that it was the only 5-year ACS available that fit the previous criteria. Although numerous 1- and 3-year ACS data exist that also meet the timing criteria, it was decided that these data were inadequate for this project as they were missing upwards of 1/3 of the counties in the study area. Furthermore, because the sample sizes of 1- and 3-year ACS were relatively small, imputation of missing counties would only lead to unreliable estimates. Likewise, the year 2000 was designated as the pre-recession year. The year 2000 model serves primarily as a historical benchmark. It is worth noting that the data were collected during the dot-com focused recession. While that recession was primarily focused on technology industries, there may have been some ripple effects felt in sectors, such as real estate and finance and insurance. However, there are no data alternatives. As before, we wanted to designate a year that did not have the 2007–2009 recession included. The decision to choose 2000 was largely data-driven. Because the ACS data series was started following the 2010 decennial census, there were no ACS available for the pre-recession period. Thus, we were forced to use the next "earliest" data set, the 2000 decennial census.

3.3.2.2 Results. Table 3.5 shows the results for the post-recession period (2016). The results for the pre-recession period can be found in Appendix B. For ease of interpretation, all coefficient estimates have been standardized. The goodness of fit statistics for the current structural model are as follows: χ^2/df is 5.8 (χ^2=388.569, df=67), CFI=1.000 and TLI=0.918 are close to 1.0, and RMSE is 0.133, all of which represent a good goodness of fit. It is important to note that the reported R^2s for industrial diversity and economic health describe how well the latent variable is described by the measured variables. As such, the closeness to 1 in this case does not describe correlation.

As seen in the results (Table 3.5), the latent variables *economic health* and *human capital* are positive and significant when regressed against total employment. The latent variable *industrial diversity* is also significant. Additionally, per the structural model, *accessibility* has a significant and positive effect on *industrial diversity* but a negative and marginally significant effect on *economic health*. All the observed variables used to measure these latent were found significant.

The sign of LQ Manufacturing is negative as expected. This indicates that an increased concentration of jobs in manufacturing over time will lead to a decrease in *industrial diversity*. Due to the state's unique location and industrial heritage, Indiana has a strong competitive advantage in manufacturing. Similarly, the sign of

TABLE 3.5
Post-Recession Period SEM Results

	Parameter Estimate	Standard Error
Structural		
Industrial Specialization		
Accessibility	0.999[3]	0.005
Economic Health		
Accessibility	-0.208[1]	0.102
Measurement		
Total Employment		
Industrial Diversity	0.455[3]	0.064
Economic Health	0.207[2]	0.074
Human Capital	0.007[3]	0.001
Industrial Diversity		
LQ Agriculture, Forestry, Fishing and Hunting	-0.240[2]	0.080
LQ Transportation and Warehousing	0.419[3]	0.075
LQ Manufacturing	-0.234[2]	0.085
Economic Health		
Unemployment (%)	0.673[3]	0.058
Household Type (%)	0.528[3]	0.060
Poverty Level (%)	0.798[3]	0.062
Human Capital		
High School Education (%)	-0.885[3]	0.060
Libraries Per Capita	-0.469[3]	0.061
Patents Per Capita	0.526[3]	0.059
Accessibility		
Population Reach 180 Miles	0.192[1]	0.080
Distance to Rail Class 1	-0.368[3]	0.081
Log (Distance to Highway Access Ramps)	0.427[3]	0.080
cov(e.perlq31,e.uemp)	0.415[3]	0.065
Cov(Human Capital, Access)	0.723[3]	0.095
	388.569 (67)	*p*-value
χ^2 (df)		0.000

[1]$p < .1$.
[2]$p < .05$.
[3]$p < .001$, R^2 Industrial Diversity = 0.99, R^2 Economic Health = 0.43.

LQ Agriculture, Forestry, and Fishing is negative and expected. As with manufacturing, Indiana has a strong competitive advantage in farming due to its geographic location and historical ties to the industry sector. As Indiana contains many rural counties in which agriculture and manufacturing jobs are prevalent, an increase in jobs in these sectors will contribute to a loss in *industrial diversity*. It is important to note that rural regions can be further divided into noncore and micropolitan counties. Manufacturing is present in micropolitan counties whereas agriculture is present in noncore counties. Alternatively, as transportation and warehousing sector jobs are less common in Indiana counties, an increase in jobs in this sector will improve *industrial diversity*. Thus, the positive sign of LQ Transportation and Warehousing is also expected.

Moreover, previous work on *industrial diversity* and economic performance identified literature with a mixed set of positive as well as negative relationships between *industrial diversity* and economic growth (Tran, 2011). For example, a study during the 1980s determined a weak but statistically significant negative correlation between industrial diversity *and unemployment rate, as expected (Attaran, 1986*). The same study also found a negative and large correlation between *industrial diversity* and per capita income, highlighting that specialization can cause higher wages for the skilled labor force. Researchers have stated that magnitude and direction of relationships will depend on the definition of *industrial diversity*, geographical unit (county, state, or U.S. Bureau of Economic Analysis region), and time period of the study, because of recessions and structural economic changes (Attaran, 1986; Tran, 2011; Wagner & Deller, 1998).

The unemployment variable is also found to be positive and significant with regards to the latent variable *economic health*. While this result may seem counterintuitive at first, it is important to note that the variable measures short term unemployment against total employment. Because the unemployment rate is defined as the percentage of job seekers who are without jobs in the last six months, a short run increase in unemployment can be a sign of market churn conditions. After six months, those without jobs are removed from the estimation of the labor force and unemployment rates. Hence, hidden unemployed adults are not captured in economic variables. This explains why unemployment rates are so low and yet there is no change in the poverty rates as well as no rise in per capita income. A strong job market, indicative of a strong regional economy, can pull people, such as retirees, homemakers, and others, who were out of the labor force back into the labor force. Note that current definitions of labor force and unemployment rate from the U.S. Bureau of Labor Statistics exclude a component known as the discouraged workers, or members of the labor force who have stopped looking for jobs in the last six months. As noted in Clark and Summers (1982) and Elmeskov and Pichelmann (1993), labor forces tend to grow the fastest when job markets are good. In other words, lured by rising wages and abundant jobs choices, more people have entered the labor market, but have not found jobs right away (Clark & Summers, 1982; Elmeskov & Pichelmann, 1993).

The results also indicate that an increase in public libraries per capita has a negative effect on *human capital* within a county. While there are numerous studies linking the contribution of public libraries to social and cultural capital (e.g., Ferguson, 2012; Goulding, 2008; Hillenbrand, 2005), there has yet been an established relationship between public libraries and human capital development in developed countries. Despite ample evidence that public libraries can promote literacy in countries such as Nigeria and Sierra Leone (Ayeni & Adepoju, 2013; Jackson, 2015), it is difficult to transfer those findings to this study because the contextual areas are so different. It could be that the opportunity cost associated with increasing the number of public libraries in Indiana counties simply outweigh the benefits that libraries may provide. Also, libraries per capita is an indicator of availability and does not show the intensity of library usage or the actual population served by the library. Additional research is needed to better understand this outcome.

As expected, patents per capita is positively associated with *human capital*. This variable is intended to measure regional innovation and entrepreneurship. These factors can imply self-employment which in turn may lead to higher total employment. However, the interpretation of the variable is not as apparent as it may seem, because patents are awarded to individuals or inventors, and the residential address of the first inventor is used (Slaper et al., 2011). This means that, while an individual may work in an urban county and earn the patent due to workplace activities, if the individual lives in a neighboring rural county, then the patent is "assigned" to the rural county. Regardless of its limitations, patents per capita can capture the distribution of inventors within rural and urban areas and be used as a proxy for innovation (Slaper et al., 2011).

The variables *population within 180 minutes* and *distance to rail class 1* measure *accessibility*. The signs of the coefficients—positive and negative, respectively—are as expected. Increases in population within three hours' drive imply larger market area due in part because of the transportation infrastructure. Increased distance to rail class 1 implies a decrease in *accessibility*, particularly for industry because, all class 1 railroads are used for freight.

This result of the model also considered a covariance between change in manufacturing location quotient and unemployment. This covariance shows that a negative value indicates a loss in concentration in manufacturing over time (i.e., a loss in jobs). As manufacturing workers tend to have lower educational attainment, a decline in the concentration of manufacturing could lead to an increase in unemployment as those workers are not educated enough to switch over to different industries. Conversely, an increase in the change in LQ for manufacturing indicates an increase in concentration of manufacturing jobs, which may lead to a decrease in unemployment—especially for regions which have traditionally relied on manufacturing industries.

4. TOOL DEVELOPMENT AND DESCRIPTION

4.1 Tool Development Overview

The developed tool incorporates both the results from the expert opinion survey (Section 3.2) and data-driven SEM (Section 3.3.2). As seen in the literature review and survey results, *transportation accessibility* is a necessary component in RER but not the sole determinant. Transportation accessibility is based on access to transportation infrastructure (i.e., distance to rail class 1 and interstate highways) and population sheds or market base (i.e., population within 180 minutes). The other components incorporated in the tool include *human capital, industrial specialization,* and *economic health*. Further discussion on the measured variables for these components may be found in Section 2.6.

The resultant tool framework is depicted in Figure 4.1 and leads to a tool that can analyze what-if scenarios should one or more of the measured variables change as a result of exogenous shocks or public policy. Furthermore, the framework also allows the tool to calculate a final resilience score for the selected geography. The initial step (steps 1–2) of the framework allows the user to select the geography they wish to analyze, which may consist of one or more Indiana counties. The user can then select which measured variables they wish to change (steps 3–5). Next, the tool determines how the change in measured variable(s) affect the [latent] component the variable is intended to measure (step 6). The last section of the framework recalculates the resilience score to aid in decision making (step 9), either as part of a multi-criteria analysis or benefit-cost accounting (step 8). It should be noted that the user can re-run the tool (or run multiple copies in tandem) to evaluate multiple project alternatives (step 7). In the context of the tool, steps 3–6 are data driven, while the final resilience score is calculated using the results from previous sections of the tool while also incorporating a weighting system based on the results from the experts' opinion survey.

4.2 Tool Structure

The tool is developed in Microsoft Excel 2016 and makes use of pivot tables and charts, in addition to macros. Due to these factors, the tool is not backwards compatible with previous versions of Excel nor outside of the Windows operating system. The tool consists of three main components, accessed via a series of sheets. The first sheet, labeled "Dashboard" consists of a county (or multiple counties') profile tool. The subsequent five sheets include the "MicroTool" components. The final sheet contains the "MacroTool" component. The "Micro Tool" and "MacroTool" allow for scenario analysis. The following subsections discuss these components in greater detail.

4.3 Dashboard

Figure 4.2 shows a screenshot of the Dashboard, which helps users understand the status of the geography they wish to analyze. The left-most panel shows the county selection menu, from which users can choose the county or counties of interest. Based on this selection, pertinent information is shown in a series of charts. It should be noted that values displayed have been rounded for ease of interpretation, and that not all displayed data are used by the tool. The Dashboard simply serves to aid users in understanding the current conditions in the region of analysis.

In clockwise order, the data displayed in the graphs include *human capital*, as measured by the percentages of persons with bachelors and high school diplomas by county, the total number of libraries per 10,000 persons, and sum of patents per 10,000 persons. The

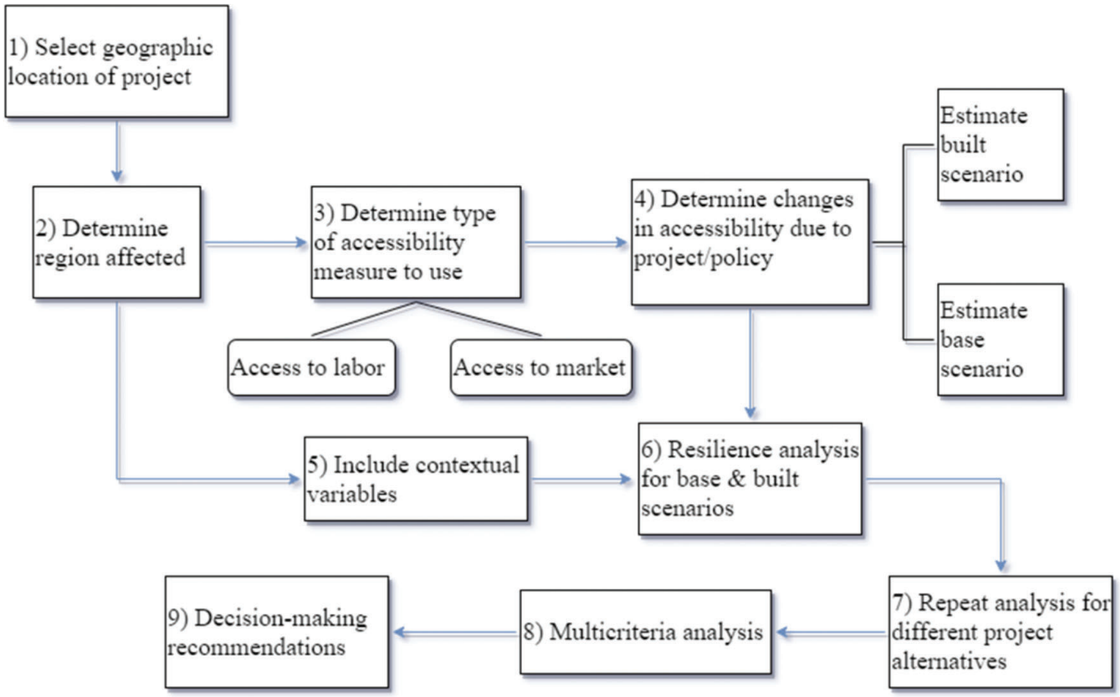

Figure 4.1 Tool development framework as applied to transportation accessibility.

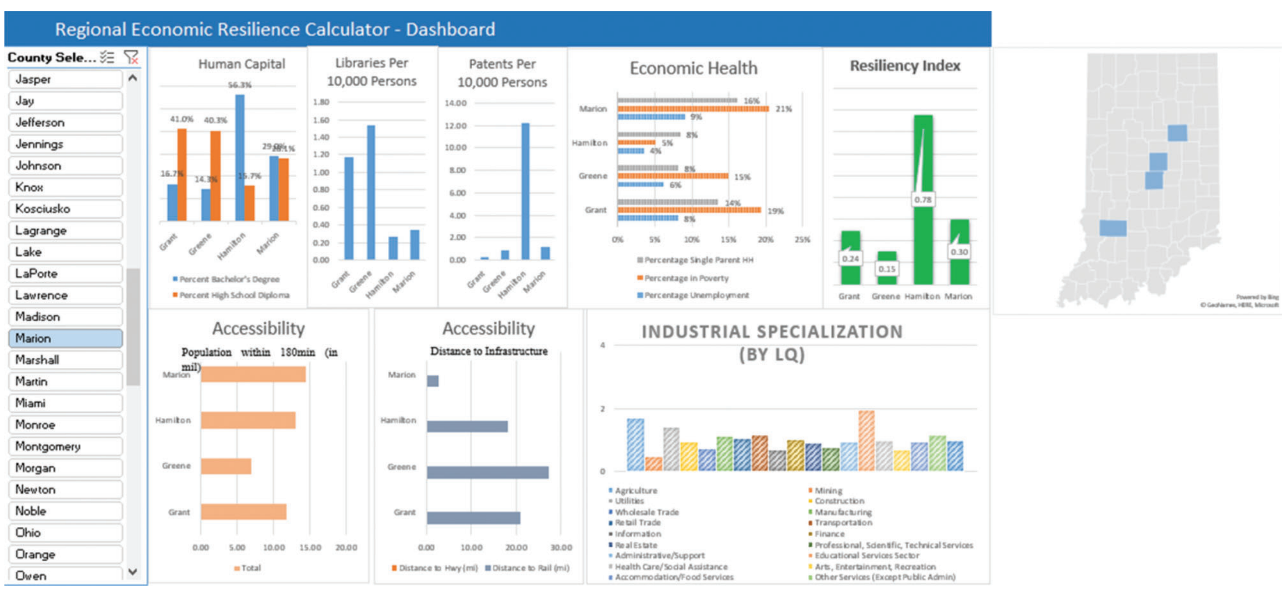

Figure 4.2 Tool dashboard.

next chart shows the *economic health* of the region, as measured by the percent of single parent households, percent of people in poverty, and the civilian unemployment rate. To the right of *economic health* is the resilience index for each selected county. Underneath is a chart containing the averaged location quotient by industry in the region. These industries are sorted by their 2-digit NAICS codes and measure *industrial specialization*. Left of that chart are two graphs that measure the *accessibility* components, distance to infrastructure (i.e., distance to highway on-ramps and distance to rail, both from a county's centroid) by county, and population within 180 minutes (in millions) by county centroid.

Finally, to the right of these charts is a map of the county. The map is powered by a Microsoft Bing search. If users select only one county, then only one county will be shown; however, if users select multiple county, as in Figure 4.2, then multiple counties are displayed. Additionally, if users select a county with a common name, the map may show the incorrect county. If this is the case, a clickable yellow icon is shown in the top right corner of the map indicating the uncertainty of the Bing county image search.

4.3.1 Scenario Analysis Tool—MicroTool

The MicroTool scenario analysis consists of five sheets. Each of the first four sheets deals with a latent component, such as *transportation accessibility* (Micro Tool_Transpo), *human capital* (MicroTool_HumanK), *industrial specialization* (MicroTool_Industry), and *economic health* (MicroTool_EconH). The last sheet in this module displays the results (MicroTool_Results). As the first four sheets are structured relatively alike, save for the display of different measured variables, only the transportation accessibility sheet is shown (Figure 4.3). Cells are color-coded as follows: cells with grey backgrounds are drawn from the data, green background cells are intended for user inputs, and blue background cells are those in which the tool displays calculated results. In the example shown, the user input value for accessibility to market has been increased; this could occur if the population of surrounding areas increased or if new transportation infrastructure allowed for greater distances traveled within the 180-minute radius (i.e., expanding the catchment area). Additional details on the use of the tool as well as images for the other components of the MicroTool may be found in the accompanying user guide.

As with the Dashboard module, users can select the county or counties to analyze. The data displayed consists of the pre-recession (year 2000) and post-recession (year 2016) values of the measured variables shown (in grey boxes). It is important to note that decimal places have been rounded to the hundredths digit. User input (i.e., values in the What If… Value column) goes in the green boxes. The index values of the control (latent) variables are calculated based on the results from SEM analysis and use the underlying data from years 2000 or 2016. Further, the new what-if driven index value is also calculated (shown in blue box). This value is calculated by multiplying the user inputs and the corresponding coefficient estimates from the SEM results.

Figure 4.4 shows the results of the MicroTool. User input(s) from the previous module(s) are used to calculate new indices for *transportation accessibility, human capital, industrial specialization*, and *economic health*. These results are also shown in the graphs underneath. In each graph, the Pre bar represents index scores based on the (year 2000) pre-recession data; the Post bar represents index scores based on the (year 2016) post-recession data; the what-if bar represents index scores based on user inputs. The index values of the four components are then used to calculate a new resilience index score.

The resilience index value is a weighted sum of the four intermediate indices, *transportation accessibility, human capital, industrial specialization*, and *economic health*. The weights used are derived from the results of the survey of experts' opinions outlined in Chapter 3. In the survey, experts were asked to rank each of the factors' contribution to resilience on a scale of none, little, moderately, strongly, and very strongly. These five rankings were assigned uniformly distributed values between 0 (none) and 1 (very strongly). The values were then summed for each of the four factors and divided by the number of responses to obtain an average response value per factor. The four average response values were then normalized to sum to unity. A higher resilience index value is associated with a region or county that is better able to withstand or overcome shocks, while a lower resilience index value is associated with a geography

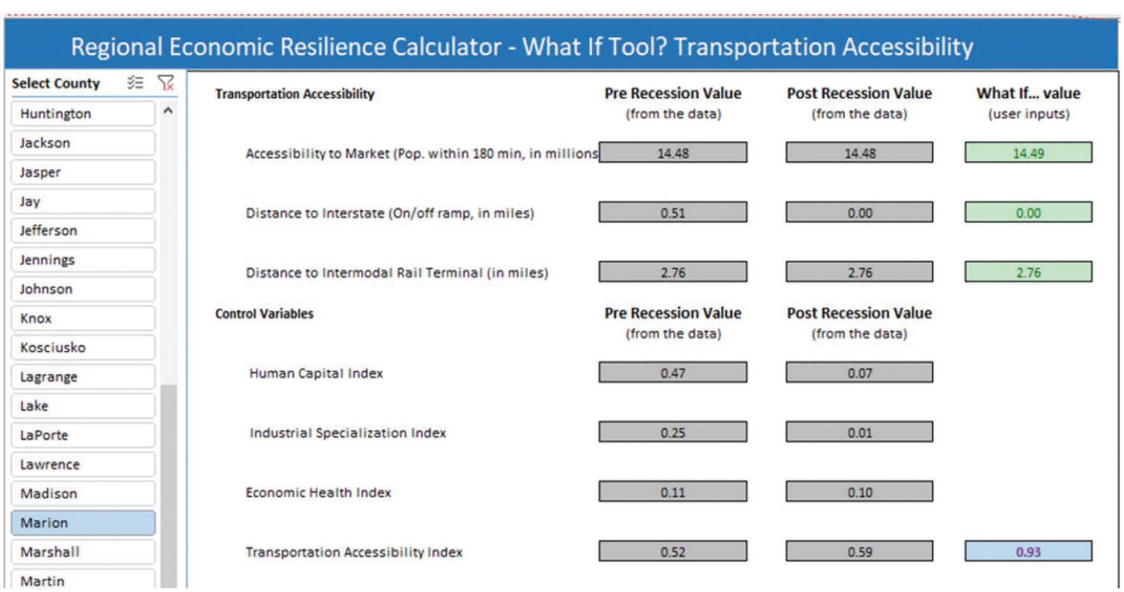

Figure 4.3 MicroTool module, transportation accessibility component.

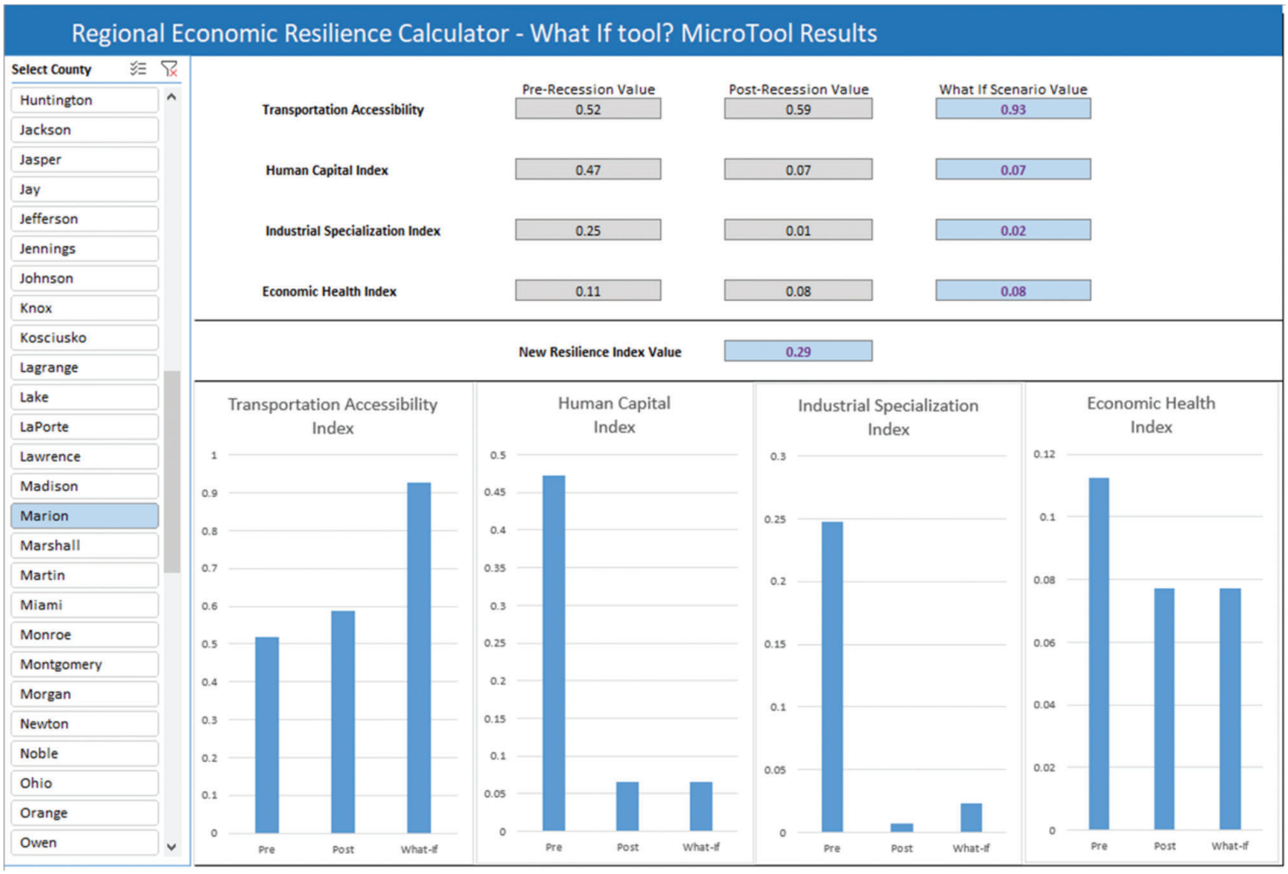

Figure 4.4 MicroTool module, results component.

that is less able to do so. Thus, in general, a high value is generally understood to be "good" or more preferable to a lower value. The following equation is used to calculate the resilience index.

$$I_{RER,i} = B_T T_i + B_H H_i + B_S S_i + B_E E_i \qquad \text{(Eq. 4.1)}$$

where,

$I_{RER,i}$ = Economic resilience index value of county i

β_T = Transportation accessibility weight, 0.27. All weights shown are rounded to the nearest hundredth and therefore do not sum to unity.

T_i = Transportation accessibility index of county i

β_H = Human capital weight, 0.26

H_i = Human capital index of county i

β_S = Industrial specialization weight, 0.27

H_i = Industrial specialization index of county i

β_E = Economic health weight, 0.21

E_i = Economic health index of county i

4.3.2 Scenario Analysis Tool—MacroTool

The MacroTool module (Figure 4.5) is functionally identical to the MicroTool in that it allows users to see how what-if scenario values affect ER. Rather than inputting values for each of the measured variables, however, users can directly input values for the four intermediate indices, *transportation accessibility, human capital, industrial specialization,* and *economic health*. The new resilience index value is then calculated following the method outlined in 4.3.1.

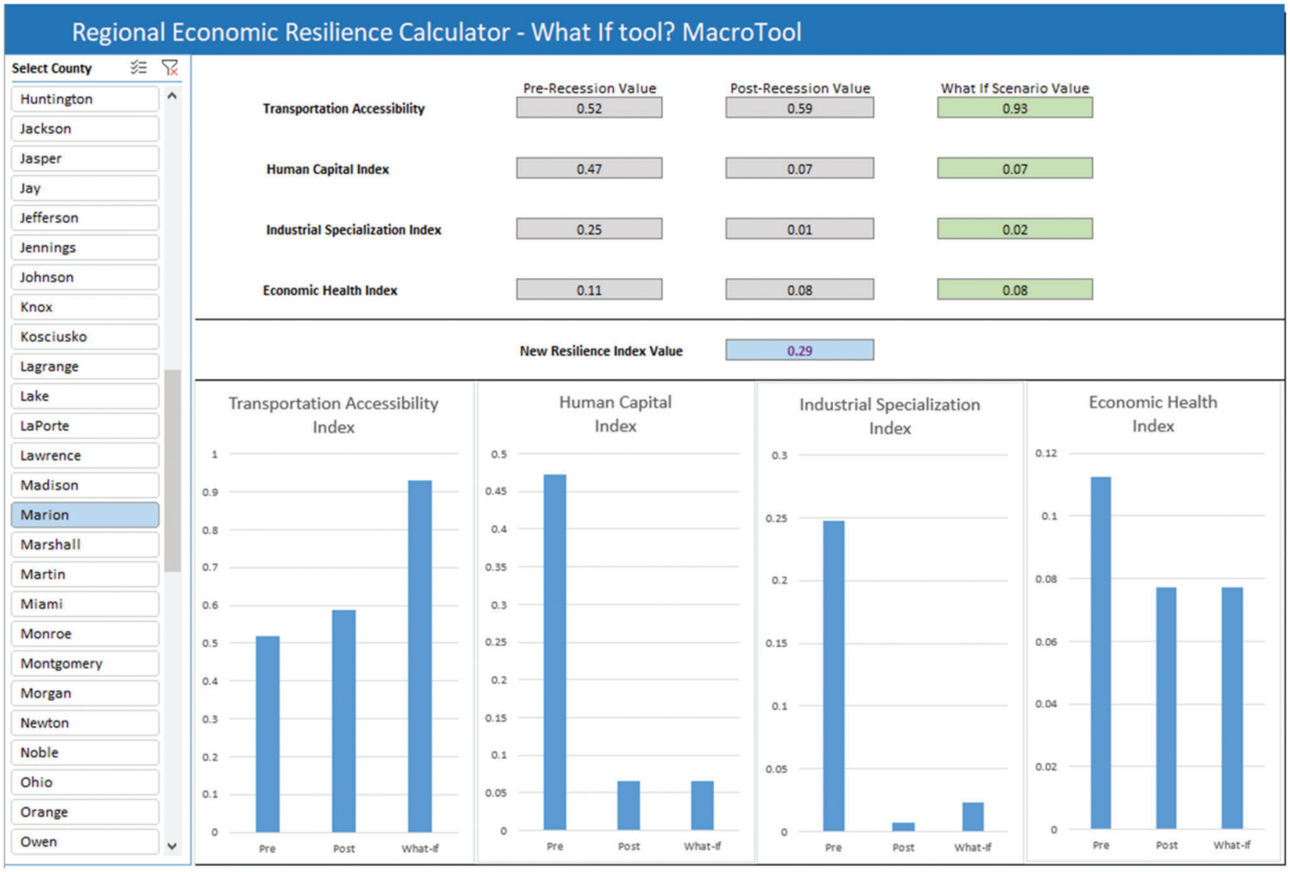

Figure 4.5 MacroTool module.

5. TOOL IMPLEMENTATION AND USE CASE EXAMPLE

5.1 Use Case Example

In lieu of a case study, this section presents a potential scenario that an end user could encounter in which this tool would help to inform policy decisions. In this example, it is assumed that the end user is in Kosciusko County, and would like to know how the Regional Economic Resilience (RER) of the county would change if a new transportation facility succeeded in attracting additional biomedical engineering firms to the area. The user would first select Kosciusko in the dashboard (Figure 5.1) to observe the current “state” of the county.

Next, the user would go to the MicroTool_Transpo tab, select Kosciusko County again, and enter new expected values for accessibility to market, distance to interstate, and/or distance to intermodal rail terminal. In this example, we assume that the access to market will increase as a result of the new transportation facility (Figure 5.2). Perhaps the new facility will allow for a greater population catchment area/labor shed, or it will entice more people to move to the area.

The user will then move to the next sheet, Micro Tool_HumanK to input new what-if values for percent high school graduate, number of public libraries per capita $\times$ 10,000, and total number of patents per capita $\times$ 10,000. In the present example, new biomedical engineering firms move to the area, leading to an increase in the total number of patents per capita (Figure 5.3).

The user then moves to the next sheets, MicroTool_Industry and MicroTool_EconH, to change location quotient and *economic health* variables, respectively. Following the use case example, it could be that an increase in biomedical engineering firms in Kosciusko county increases manufacturing jobs hence increasing the location quotient (Figure 5.4). However, the case used in the example does not affect *economic health* variables (Figure 5.5). In the case that *economic health* variables were affected, users can opt to change values for percent of families with female head of household, percent of people of all ages in poverty, and civilian labor force unemployment rate. For a project that aimed to increase employment in a county, for instance, the user can input the projected decreased the unemployment rate to capture that change.

After having put in new values for the what-if scenario, the user goes to the final sheet of the Micro Tool to see the results (Figure 5.6). On this sheet, the user can examine the what-if scenario’s intermediate indices as well as the new resilience index. Following the use case example, increases in the accessibility to market, number of patents per capita, and location

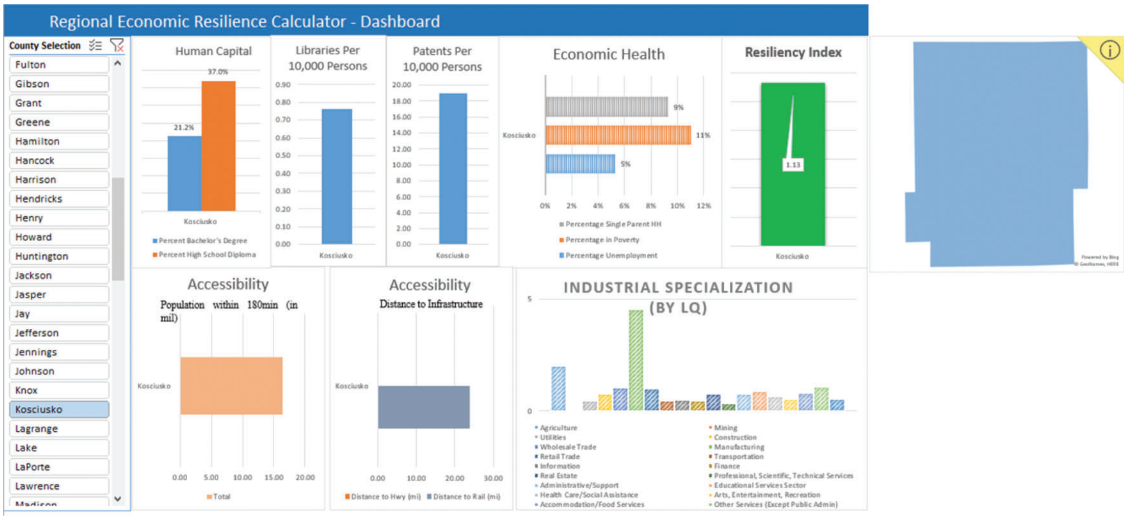

Figure 5.1 Use case example—dashboard.

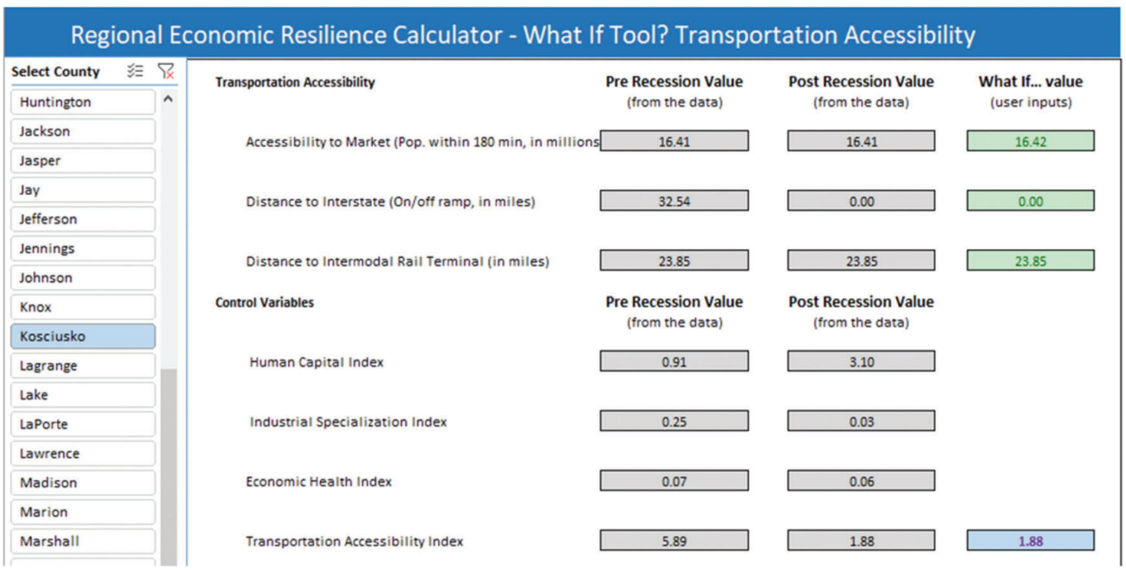

Figure 5.2 Use case example—MicroTool_Transpo Sheet.

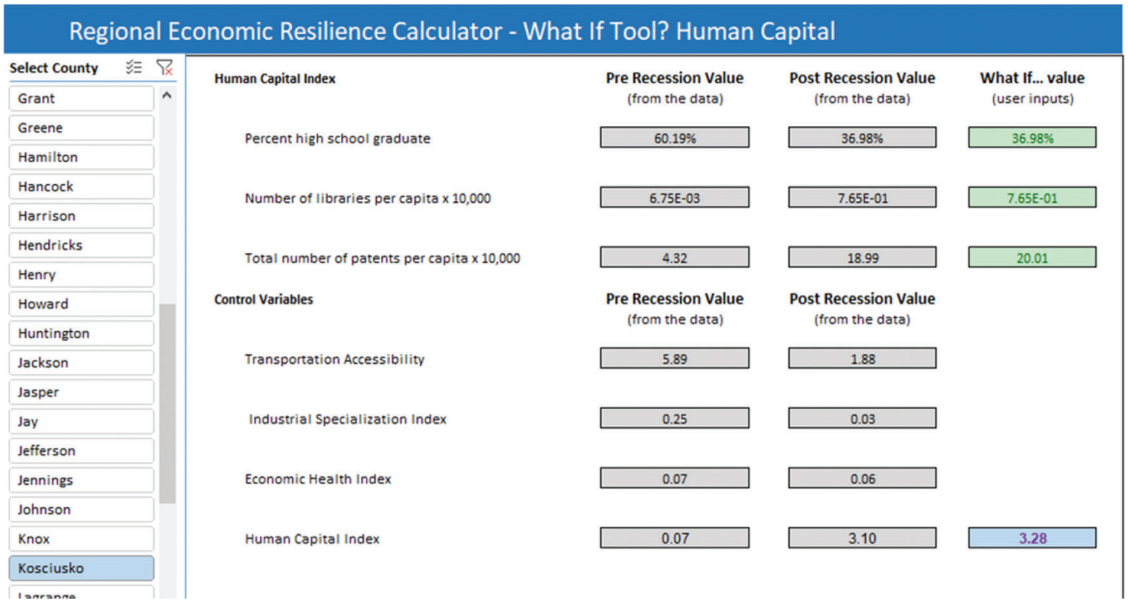

Figure 5.3 Use case example—MicroTool_HumanK Sheet.

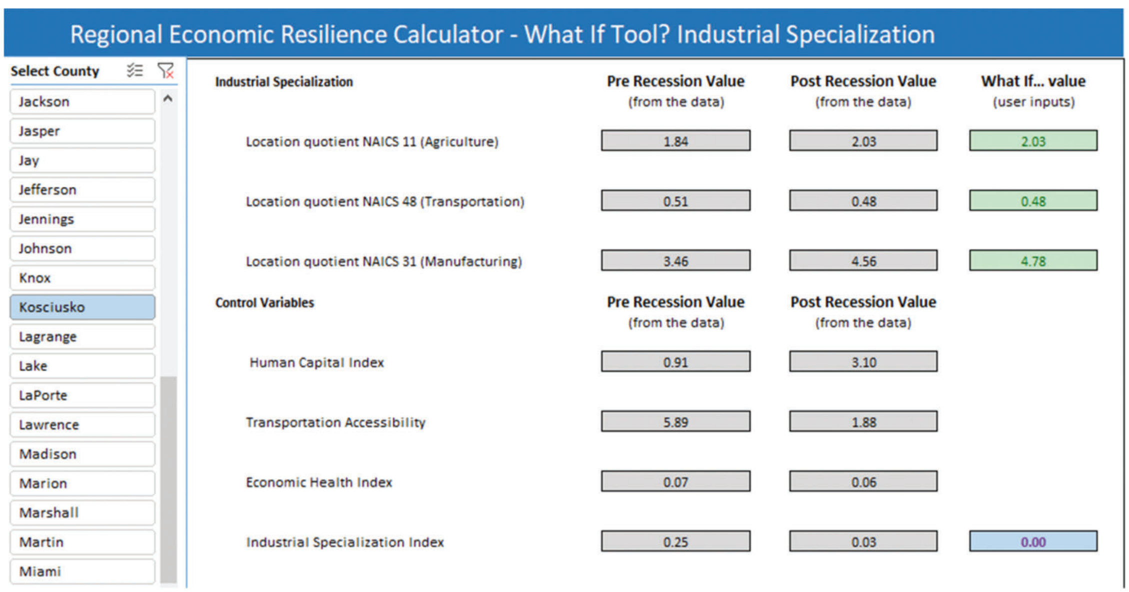

Figure 5.4 Use case example—MicroTool_Industry.

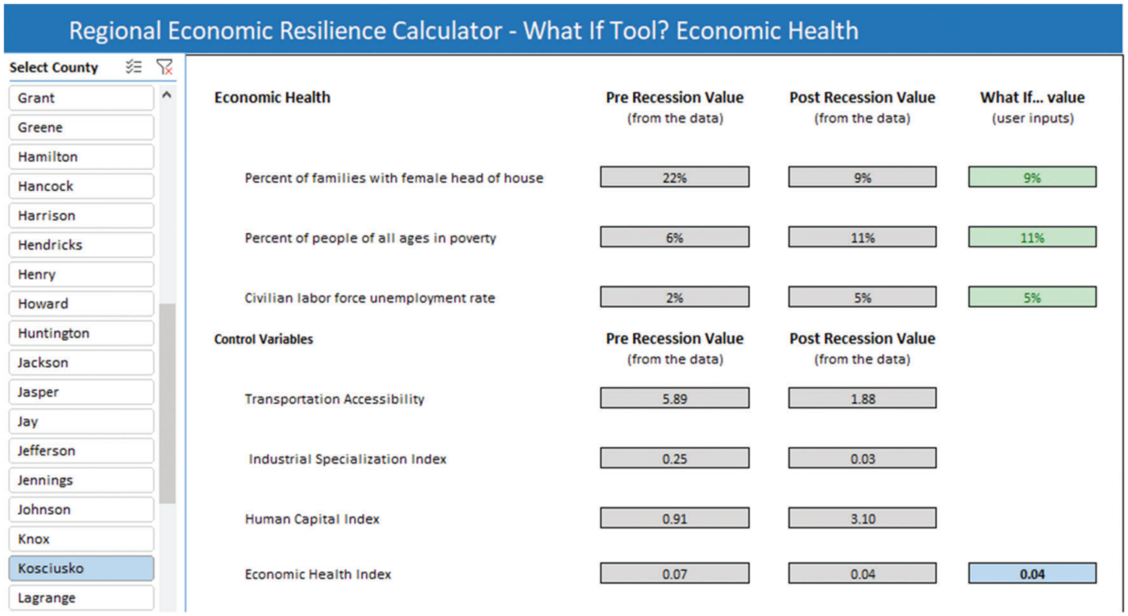

Figure 5.5 Use case example—MicroTool_EconH.

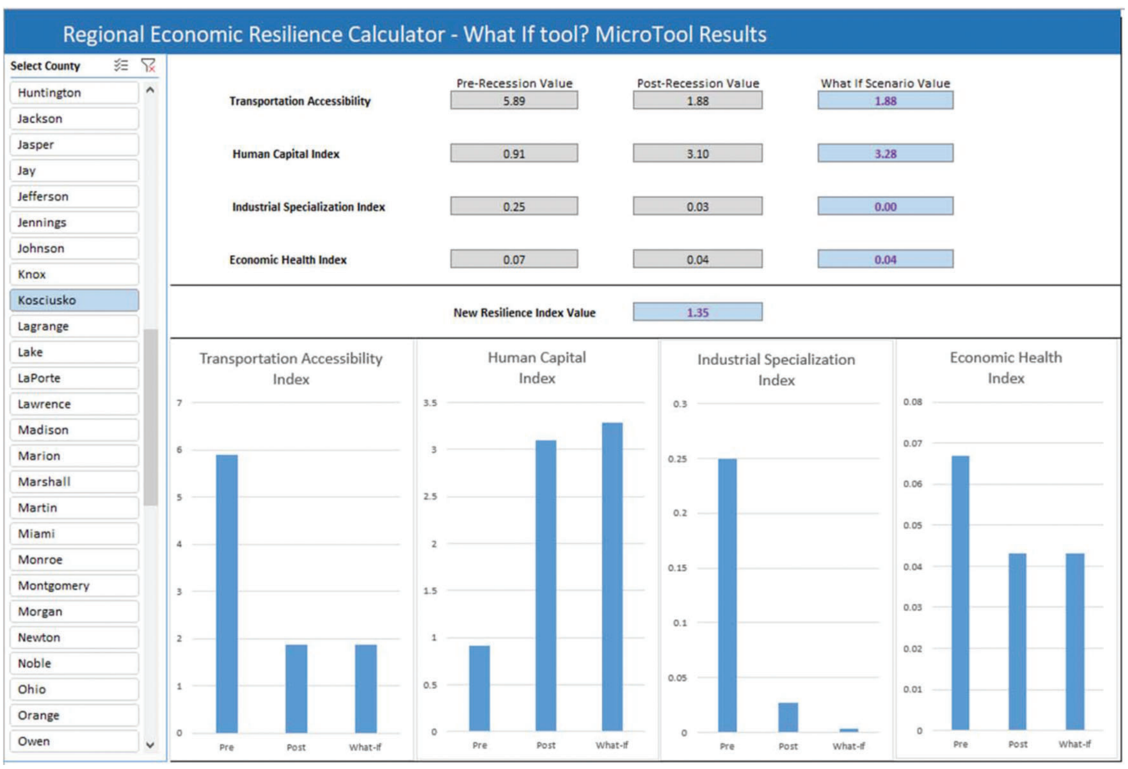

Figure 5.6 Use case example—MicroTool Results.

quotient to manufacturing leads to recalculations of the intermediate indices, as well as a calculation of the resilience index. As a higher resilience index value indicates that a county or region is more resilient, these results indicate that Kosciusko County will be more resilient in the what-if scenario than it is in the current state. However, it should be noted that results are rounded to the nearest hundredths; therefore, it may appear that no change in resilience occurred.

Alternatively, if the users already have a rough idea of how the intermediate indices will change, they can use the MacroTool and directly input those values in order to calculate the new resilience index value (Figure 5.7).

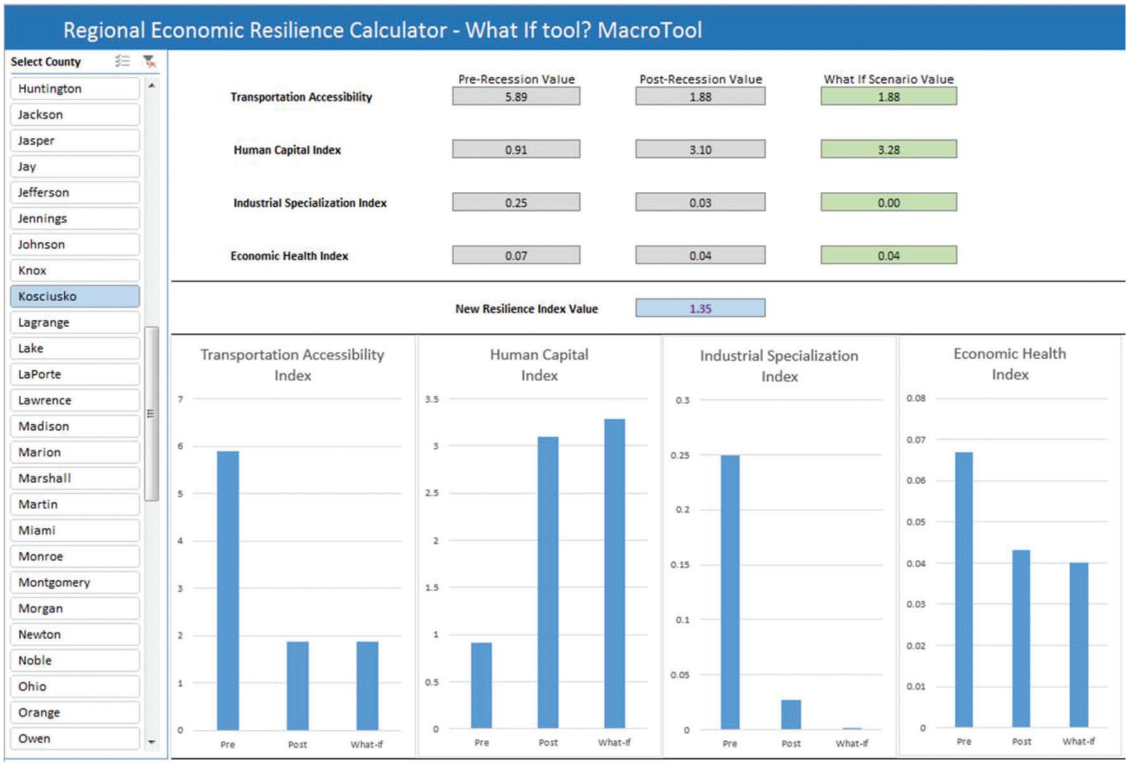

Figure 5.7 Use case example—MacroTool.

6. DISCUSSION

6.1 Conclusions

From the survey analysis, significant conclusions arose. The experts in Indiana are aware of the term and concept of Regional Economic Resilience (RER), but it is inferred they have not found an easy and applicable way to apply the concept in their everyday practice. Additionally, from their perspective, transportation and ER are related. Moreover, experts classified this relationship as strong. This finding confirms that from the decision-makers' perspective, transportation plays a vital role and it should be considered when discussing the ER of regions. Finally, the survey results reinforce that RER does not depend only on transportation-related factors (such as access to labor markets), but it is the result of complex relationships that involve other components such as *human capital and industrial diversity*, among others.

From the quantitative analysis, it was found that the interdependencies among the different components were supported by the structural equation model outcomes. Additionally, the measurement model showed that the variables selected in the exploratory factor analysis are reliable to represent the four-construct analyzed. Those results were consequently used to develop the RER tool. The following sections discuss ways in which the tool can be used at the policy and project planning levels.

6.2 Implementation Potential

The deliverables stemming from this project can be used to help inform policy makers and transportation planners at the metropolitan, county/regional, and state levels with empirically driven predictions of how potential projects will affect regional economic resilience. Stakeholders can use this information to develop more robust benefit cost analyses to evaluate potential projects or policy interventions as part of a multiple criteria decision-making process. Furthermore, because of the multitude of factors incorporated within the RER estimator spreadsheet tool, potential projects are not limited to solely traditional transportation projects such as improvements to highway infrastructure or increasing labor market access. Another potential use case is to evaluate the impact of multiple interventions simultaneously on regional economic resilience via the tool. The following sections discuss in greater detail the implementation potential of this project's products as it may pertain to an example study area.

6.2.1 Incorporation of Resilience Index at the Policy Level

Although policy making tends to follow region-specific habits and cultural mentalities (Wink, 2014), the goals of policies related to resilience seem to have important commonalities across different geographical areas. Notwithstanding these similarities at the policy level, the implementation of those policies in order to enhance resilience will still be highly dependent on the political and institutional arrangements of each region.

The literature reviewed in Section 2 and model results from Section 3 illustrate that the resilience behavior of regions results from the blending of various components (e.g., *industrial diversity* and *human capital)*. At the policy level, Bristow and Healy, (2014) discuss three types of interventions: reactive, responsive, and preventive measures. The reactive measures refer to those actions taken to reduce the effects of recessions on firms and individuals. An example of reactive measures include investments in transportation, civil, or social infrastructure (Wink, 2014) aiming to reduce or alleviate the impacts of the shocks. The responsive measures are taken when the reactive measures are overcome by the effects of the recession. An example of responsive measures includes strengthening emerging technologies (new market infrastructures) (Wink, 2014) that complement the reactive measures. Finally, the preventive measures are those aiming to reduce or avoid the risk of the occurrence of future shock. An example of preventative measures includes industry diversification processes and workforce development that generate changes in the structural factors in the economic and urban systems.

Users of the MicroTool can incorporate these three types of interventions in their scenario planning. Suppose that the study area mentioned at the beginning of Section 6.2 won a bid to have a major transportation warehousing facility constructed within its urban growth boundary (i.e., a reactive measure when hiring local construction workers, and a responsive measure as the facility would employ workers once it is built). Suppose also that the local school district embarked on a program designed to help high school seniors graduate on time (i.e., a preventative measure). Regional planners could use the MicroTool to predict how the increase of jobs in the transportation and warehousing sector as well as expected increase in high school graduation rates would affect economic resilience.

6.2.2 Resilience at the Project Level

Although the discussion about frameworks that could be applied at the project level is limited in the literature, there are some case studies where the benefits of resilience-related policies are documented. At the local level, transportation is seen as an economic asset that links the labor workforce, resources, and markets, as well as a key component to support community livability. Therefore, improvements in transportation infrastructure also mean improvements in access to education, employment, and other essential services that, in the long run, support economic and quality of life outcomes (NADO, 2016). These constitute the main link between transportation and the resilience benefits. For instance, the previously mentioned example study area could be located near a major city experiencing a population boom. This would mean that the transportation accessibility to the study area has improved, as the area's potential labor shed (i.e., population within 180 minutes) has grown. Regional planners can then use the tool to predict how this change affects local economic resilience.

The development of resilience-related strategies and metrics are not necessarily new at the regional level because Comprehensive Economic Development Strategies (CEDS), as required by the U.S. Economic Development Administration, are already a venue where these types of measures are discussed in the context of regional planning. CEDS are required to incorporate resilience-related strategies. However, very few CEDS have achieved this. Some CEDS have mentioned about economic resilience but have not achieved the integration between project and program selection and the economic resilience. More specific to transportation, NADO (2018) recommends the implementation of performance-based approaches of economic well-being in transportation plans and prioritization processes. The MacroTool module of the tool may be used by stakeholders to assist with such planning processes, because it allows users to easily analyze the effects that multiple strategies will have simultaneously through its use of intermediate indices rather than be limited by the set of strategies explicitly included in the MicroTool modules.

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APPENDICES

Appendix A. Survey Questionnaire

Appendix B. SEM Results (2000 Values)

Appendix C. Glossary of Terms Used in the Tool

APPENDIX A. SURVEY QUESTIONNAIRE

Components of Economic Resilience Survey (Informed Consent)

What is the purpose of this study? Purdue University and the Indiana Department of Transportation (INDOT) are conducting a study to incorporate metrics of Economic Resilience into the selection and decision-making of transportation projects in Indiana under the JTRP Project SPR 4162. As such, this survey has been designed with three main objectives: (1) to determine stakeholders' level of awareness of the concept of regional economic resilience; (2) to determine the extent to which the concept of regional economic resilience or similar considerations are included as part of the project planning or decision-making process; and (3) to identify how the different components influencing regional economic resilience are interrelated.

What will I do if I choose to be in this study? If you choose to participate in this study, you will be asked to answer questions related to your professional experience with project planning and to give your opinion about the interdependencies between components of regional economic resilience.

How long will I be in the study? The survey will take less than 10 minutes to complete.

Will information about me and my participation be kept confidential? Your responses will be completely confidential and anonymous. You will not be asked to disclose any sensitive information including your age, ethnicity, education level, income, employment records, etc. This survey is exempt under IRB Protocol #1803020346.

Will I receive payment or other incentives? Participants will be asked to volunteer their time to complete the questionnaire for no compensation.

What are my rights if I take part in this study? Your participation in this study is voluntary and you can withdraw your participation at any time without any penalty or loss of benefits to which you are otherwise entitled.

Who can I contact if I have questions about the study? If you have questions, comments, or concerns about this research project, please contact one of the researchers: Lisa Losada at llosadar@purdue.edu or Davis Chacon-Hurtado at dchaconh@purdue.edu.

Consent. By clicking next in the lower right portion of your screen, you indicate that you have read and understood the information provided above, that you willingly agree to participate, and that you are aware that you may withdraw your consent at any time and discontinue your participation without penalty. If you choose not to participate, simply close your web browser.

Section I

Please indicate the type of organization where you work:

- ◯ Rural Planning Organization (RPO) (1)
- ◯ Metropolitan Planning Organization (MPO) (2)
- ◯ Department of Transportation (3)
- ◯ Research or academic institution (4)
- ◯ Private firm (please specify type): (5) ____
- ◯ Other (please specify): (6) ____

Which of the following options best describe your role in the decision making process for transportation projects?

- ◯ Decision-maker (1)
- ◯ Advisory role as (please specify): (2) ____
- ◯ Other (please specify): (3) ____

How many years of work experience do you have approximately?

- ◯ 1–3 years (1)
- ◯ 4–6 years (2)
- ◯ 7–9 years (3)
- ◯ 10–12 years (4)
- ◯ 13 years or more (5)

Section II

Are you familiar with the concept of “regional economic resilience”?

- ◯ Not at all (1)
- ◯ I have heard about it (2)
- ◯ Yes, but I don’t use it regularly (3)
- ◯ Yes, I use it regularly (4)
- ◯ Uncertain / don’t know (5)

Section III

In your opinion, to what extent each of the following components affects *Economic Resilience*? Click link for *Definitions*.

	Not at All (1)	Little (2)	Moderately (3)	Strongly (4)	Very Strong (5)
Human Capital (1)	○	○	○	○	○
Industrial Diversity (2)	○	○	○	○	○
Entrepreneurship (3)	○	○	○	○	○
Livability (4)	○	○	○	○	○
Social Capital (5)	○	○	○	○	○
Macroeconomic Conditions (6)	○	○	○	○	○
Accessibility to Labor and Markets (7)	○	○	○	○	○
Infrastructure (energy, health, transportation) (8)	○	○	○	○	○
Other (optional) (9)	○	○	○	○	○
Other (optional) (10)	○	○	○	○	○

In your opinion, to what extent does ***human capital*** influence? Click link for *Definitions*.

	Extremely Negative -3	Moderately Negative -2	Slightly Negative -1	Neither Positive nor Negative 0	Slightly Positive 1	Moderately Positive 2	Extremely Positive 3
Industrial Diversity ()							
Entrepreneurship ()							
Livability ()							
Social Capital ()							
Macroeconomic Conditions ()							
Accessibility to Labor and Markets ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***industrial diversity*** influence? Click link for *Definitions.*

	Extremely negative -3	Moderately negative -2	Slightly negative -1	Neither positive nor negative 0	Slightly positive 1	Moderately positive 2	Extremely positive 3
Human Capital ()							
Entrepreneurship ()							
Livability ()							
Social Capital ()							
Macroeconomic Conditions ()							
Accessibility to Labor and Markets ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***entrepreneurship*** influence? Click link for *Definitions*.

	Extremely Negative -3	Moderately Negative -2	Slightly Negative -1	Neither Positive nor Negative 0	Slightly Positive 1	Moderately Positive 2	Extremely Positive 3
Human Capital ()							
Industrial Diversity ()							
Livability ()							
Social Capital ()							
Macroeconomic Conditions ()							
Accessibility to Labor and Markets ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***livability*** influence? Click link for *Definitions*.

	Extremely Negative -3	Moderately Negative -2	Slightly Negative -1	Neither Positive nor Negative 0	Slightly Positive 1	Moderately Positive 2	Extremely Positive 3
Human Capital ()							
Industrial Diversity ()							
Entrepreneurship ()							
Social Capital ()							
Macroeconomic Conditions ()							
Accessibility to Labor and Markets ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***social capital*** influence? Click link for *Definitions*?

	Extremely Negative -3	Moderately Negative -2	Slightly Negative -1	Neither Positive nor Negative 0	Slightly Positive 1	Moderately Positive 2	Extremely Positive 3
Human Capital ()							
Industrial Diversity ()							
Entrepreneurship ()							
Livability ()							
Macroeconomic Conditions ()							
Accessibility to Labor and Markets ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***macroeconomic conditions*** influence? Click link for *Definitions*.

	Extremely Negative -3	Moderately Negative -2	Slightly Negative -1	Neither Positive nor Negative 0	Slightly Positive 1	Moderately Positive 2	Extremely Positive 3
Human Capital ()							
Industrial Diversity ()							
Entrepreneurship ()							
Livability ()							
Social Capital ()							
Accessibility to Labor and Markets ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***accessibility to labor and markets*** influence? Click link for *Definitions*.

	Extremely Negative	Moderately Negative	Slightly Negative	Neither Positive nor Negative	Slightly Positive	Moderately Positive	Extremely Positive
	-3	-2	-1	0	1	2	3
Human Capital ()							
Industrial Diversity ()							
Entrepreneurship ()							
Livability ()							
Social Capital ()							
Macroeconomic Conditions ()							
Infrastructure (energy, health, transportation) ()							

In your opinion, to what extent does ***infrastructure (energy, health, transportation)*** influence? Click link for *Definitions*.

	Extremely Negative	Moderately Negative	Slightly Negative	Neither Positive nor Negative	Slightly Positive	Moderately Positive	Extremely Positive
	-3	-2	-1	0	1	2	3
Human Capital ()							
Industrial Diversity ()							
Entrepreneurship ()							
Livability ()							
Social Capital ()							
Macroeconomic Conditions ()							
Accessibility to labor and markets ()							

Table A.1 Definitions

Component	**Description**
Industrial Diversity	It refers to the degree to which the industrial base of a region is concentrated in a few or various economic sectors. It usually refers to the share of jobs in each industry sector within a region.
Human Capita	It refers to the knowledge “stocks” or characteristics that an individual has inherited or acquired that contributes to his or her development within a socio-economic system (e.g., level of education).
Entrepreneurship	It corresponds to the flexibility and attitude that people possess to innovate and invest in ideas and business while assuming all the risks and rewards of the venture. Entrepreneurs typically start and their own business and services.
Social Capital	It is sum of resources that accrue to an individual or a group by a network of relationship of mutual acquaintance and recognition. It could be interpreted as the “glue” that holds communities together and brings benefits to the entire group.
Livability	It refers to the factors that add up to a community’s quality of life. It includes the natural and built environment that creates safe, comfortable, and accessible places for people of all ages.
Macroeconomic Conditions	It refers to the “health” or status of a regional economy prior the recession. It includes measures of economic growth, employment, and economic stability.
Infrastructure	It refers to the level of access and quality of basic services such as communications, energy, and health services. Transportation is also included in this category.
Accessibility to Labor and Markets	It refers to the amount of opportunities (e.g., services, activities, labor, and customers) that are available for people and firms through the transportation system. It also refers to the amount of transportation infrastructure available within a region.

APPENDIX B. SEM RESULTS (2000 VALUES)

This model considered the 2000 U.S. Census as main dataset. As mentioned in the text, it intended to resemble the behavior of the variables of analysis before the recession. For ease of interpretation, all coefficient estimates have been standardized. The goodness of fit statistics for the current structural model are as follows: χ^2/df is 7.14 (χ^2= 478.579, df=67), CFI=1.000 and TLI=0.876 are close to 1.0, and RMSE is 0.256, all of which represent an okay goodness of fit.

Table B.1 Pre-Recession Period SEM Results

	Parameter Estimate	**Standard Error**
Structural		
Industrial Diversity		
Accessibility	0.999[3]	0.005
Economic Health		
Accessibility	0.004	0.097
Measurement		
Total Employment		
Industrial Diversity	0.002[3]	0.002
Economic Health	0.091[3]	0.009
Human Capital	0.007[3]	0.001
Industrial Diversity		
LQ Agriculture, Forestry, Fishing and Hunting	-0.0144[3]	0.006
LQ Transportation and Warehousing	-0.006[3]	0.002
LQ Manufacturing	-0.009	0.350
Economic Health		
Unemployment (%)	0.707[3]	0.001
Household Type (%)	0.068[3]	0.003
Poverty Level (%)	0.108[3]	0.005
Human Capital		
High School Education (%)	-0.006	0.1798
Libraries per Capita	-0.376[2]	0.141
Patents per Capita	0.283	0.175
Accessibility		
Population Reach 180 Miles	0.171[3]	0.007
Distance to Rail Class 1	-0.152	0.539
Log (distance to highway access ramps)	0.178[2]	0.076
cov(e.perlq31,e.uemp)	0.020	0.912
Cov(Humanc, Access)	0.019[3]	0.207
χ^2 (df)	388.569 (67)	*p*-value

[1] $p < .1$
[2] $p < .05$
[3] $p < .001$, R^2 Industrial Diversity=1, R^2 Economic Health= 0.32.

APPENDIX C. GLOSSARY OF TERMS USED IN THE TOOL

Transportation Accessibility Variables	
Accessibility to Market (population within 180 min, in millions)	This value is calculated via ArcGIS and captures the market catchment area within a 180-min drive (network distance) of the county centroid point.
Distance to Interstate (on/off ramp, in miles)	This value is calculated via ArcGIS, and is equal to the network distance (in miles) from the county centroid to the nearest interstate on or off ramp.
Distance to Intermodal Rail Terminal (in miles)	This value is calculated via ArcGIS, and is equal to the network distance (in miles) from the county centroid to the nearest rail class 1 terminal.
Human Capital Variables	
Percent High School Graduate	This value represents the percentage of persons in a county over the age of 25 whose highest education received is that of a high school graduate. This data comes from the U.S. Census Bureau's 5-year 2016 American Community Survey.
Number of Libraries per Capita (×10,000)	This value is equal to the number of public libraries per capita, multiplied by 10,000 in each county.
Total Number of Patents per Capita (×10,000)	This value is equal to the total number of patents attributed to each county divided by the number of persons in that county and multiplied by 10,000. This data comes from the U.S. Patent Office. It should be noted that patents are geolocated to the patent filer's home address.
Industrial Specialization Variables	
Location Quotient NAICS 11 (Agriculture)	This value represents the location quotient of Agriculture, Forestry, and Fishing (NAICS 11) jobs for each county. The data is from Emsi.
Location Quotient NAICS 48 (Transportation)	This value represents the location quotient of Transportation and Warehousing (NAICS 48-49) jobs for each county. The data is from Emsi.
Location Quotient NAICS 31 (Manufacturing)	This value represents the location quotient of Manufacturing (NAICS 31-33) jobs for each county. The data is from Emsi.
Economic Health Variables	
Percent of Families with Female Head of House	This value is the percent of families with a female head of house at a county level. The data comes from the U.S. Census Bureau's 5-year 2016 American Communities Survey.

Percent of people of All Ages in Poverty	This value is the percentage of people of all ages in poverty at a county level. The data comes from the U.S. Census Bureau's 5-year 2016 American Communities Survey.
Civilian Labor Force Unemployment Rate	This value is the unemployment rate of the civilian labor force at a county level. The data comes from the U.S. Census Bureau's 5-year 2016 American Communities Survey.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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