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The Use of Resilience in Regional Science: A Discussion of Some Contested Issues

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Abstract: The concept of resilience has now been widely adopted across the social sciences and has assumed prominence in regional science. While this growing attention is to be welcomed, it has also given rise to ambiguity and confusion within the existing regional science literature, especially regarding foundational questions and, consequently, to the policy implications of resilience. Using probability theory, this paper offers an analysis of three foundational and one policy-related issues associated with the use of resilience in regional science. The foundational issues address questions of definition, whether resilience should be understood as a process, and if resilience should invariably be regarded as desirable. The policy-related issue focuses on the related concepts of resilience and sustainability. The paper concludes with two recommendations about future research on resilience in regional science.

Keywords: Equilibrium, Probability Theory, Process, Resilience, Sustainability

JEL Codes: Q57, R11, R58

1. INTRODUCTION

The concept of resilience has become a central organizing idea in contemporary regional science, shaping analyses of regional growth, decline, and recovery in the face of shocks (Christopherson et al., 2010). Yet despite its popularity, the uncritical adoption of resilience raises important conceptual and methodological concerns (Batabyal, 2023). A critical examination is especially warranted once one understands that the post-World War II scientific use of resilience originated not in the social sciences but in ecology, most notably in the seminal contribution of Holling (1973) and later in the influential paper by Pimm (1984). The ecological roots of the concept highlight both its analytical strengths and its limitations when transplanted into regional science.

In Holling's (1973) framework, resilience—also called ecological resilience—refers to the capacity of an ecosystem to absorb disturbances and reorganize while retaining its core structure and function. This interpretation was explicitly contrasted with notions of equilibrium stability, emphasizing nonlinearity, thresholds, and multiple stable states. In contrast, the Pimm (1984) notion of resilience—also called engineering resilience—focuses more narrowly on return times and local stability around an equilibrium. The coexistence of these distinct

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ecological interpretations tells us that resilience is a contested and multifaceted concept even within its original disciplinary home. When regional scientists import resilience without carefully specifying which interpretation they are using, conceptual ambiguity is almost inevitable (Batabyal and Kourtit, 2021).

One major problem in regional science is definitional looseness. Resilience is often used interchangeably with resistance, recovery, adaptability, or even long-run growth performance. Such elasticity makes the concept rhetorically appealing but analytically weak. Unlike ecological systems, regions are composed of purposeful agents, institutions, power relations, and political processes (Brunckhorst, 2002). Treating regions as if they are ecosystems risks obscuring these social dimensions and replacing explanation with metaphor. In this sense, resilience sometimes functions more as a descriptive label applied after the fact than as a rigorously specified analytical construct (Pendall et al., 2010).

A second concern is the normative drift of the concept. In ecology, resilience is not inherently good (Walker, 2020). Highly resilient ecosystems can lock in undesirable states. In regional science, however, resilience is frequently treated as an unambiguously positive attribute, something policymakers should always seek to enhance. This line of thinking is problematic. A region may be resilient precisely because it reproduces disagreeable phenomena such as inequality, environmental degradation, or even institutional inertia. By celebrating resilience without asking "resilience of what and for whom?" regional science runs the risk of endorsing the continuity of socially undesirable outcomes (Saulnier and Topp, 2024).

Policy relevance presents a further challenge. The reference to multiple stable states in the Holling (1973) notion of resilience has been picked up in regional studies of path dependence and lock-in (Martin and Sunley, 2006). Yet policy prescriptions derived from resilience thinking are often vague. Calls to "build resilience" rarely translate into concrete guidance on which instruments to use, how to prioritize competing objectives, or how to manage trade-offs with efficiency and equity. Moreover, the connection between resilience and sustainability is frequently commented on but not discussed meaningfully (Perrings, 1996, 2006).

Given this state of affairs, our central claim is that some of the existing literature on resilience in regional science is *not* marked either by conceptual transparency or terminological clarity on foundational issues. As such, we have two interrelated objectives in this paper. First, using probability theory, we discuss three noteworthy facets of resilience studies that have led to some ambiguity or confusion. To this end, in section 2, we concentrate on the definition of the notion of resilience. In section 3, we explain whether the notion of resilience is a process or a characteristic of a socioeconomic system. In section 4, we comment on whether the resilience of a socioeconomic system is always a good thing that is worthy of promotion. Second, and once again using probability theory, in section 5, we discuss the nexuses between the two notions of resilience and sustainability. Finally, in section 6, we conclude and then suggest two ways in which the research delineated in this paper might be extended.

2. DEFINITIONS

2.1. Two Interpretations of Resilience

When we look at the modern or post-World War II era, we see that the concept of resilience was first introduced and popularized in ecology by Holling (1973). This notwithstanding, resilience now has two meanings in ecology. This point needs to be understood by regional scientists, keeping in mind the related point that they are typically studying socioeconomic and not ecological systems. This is salient because, unlike ecological systems, the socioeconomic systems that regional scientists standardly study are made up of purposeful agents, institutions, power relations, and political processes.

Unless regional scientists understand how resilience has been used previously in the ecology literature, there is the distinct danger that they will either use this concept inappropriately and/or give it a new meaning and thereby contribute to its use as a buzzword that delineates something that sounds good but has multiple meanings to multiple researchers. In this regard, Alexander (2013) has appositely pointed out that "it is striking how the term is used in different disciplines without any reference to how it is employed in other fields, as if there were nothing to learn or transfer from one branch of science to another." In other words, regional scientists who are unaware of the prior use of resilience in ecology may end up either "reinventing the wheel" or endorsing a perspective that does not engender the cross-fertilization of knowledge across different disciplines.

Let us now discuss the two meanings of resilience. First, we have *engineering* resilience or resilience of the first kind. Here, even though C.S. Holling (1996) came up with the term engineering resilience, resilience in this particular sense originates from the work of Pimm (1984). Other researchers who have contributed greatly to the development of engineering resilience include O'Neill et al. (1986) and Tilman and Downing (1994).

Second, we have *ecological* resilience or resilience of the second kind. This second sense in which the notion of resilience has been and is used in ecology is due to Holling (1973). It is important to understand that engineering resilience and ecological resilience are very different concepts, and hence, in general, one does not expect there to be any obvious relationship between these two dissimilar ideas.

To see exactly how these two notions of resilience are different from each other, let us consider standard definitions of these two concepts. In this regard, engineering resilience "concentrates on stability near an equilibrium steady state, where resistance to disturbance and speed of return to the equilibrium are used to measure the property. . . " (Holling, 1996). In contrast, ecological resilience "emphasizes conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behavior—that is, to another stability domain" (Holling, 1996). From these two definitions, it should be clear to the reader that, *inter alia*, engineering resilience is an "equilibrium-centered" view of an ecosystem and that ecological resilience is a "far-from-equilibrium" view of an ecosystem.

The work of Pimm (1991) and Perrings et al. (1995) informs us that both these notions of resilience are pertinent when analyzing the responses of ecosystems to shocks. In addition, the work of Perrings (1987, 1991) and that of Batabyal (1998, 1999a,b, 2001) tells us that these two notions are also relevant when analyzing jointly determined ecological-economic systems such as fisheries, forests, and rangelands.[1] That said, the key question is this: Are these two notions of resilience useful as organizing concepts for socioeconomic systems which are the systems that regional scientists routinely work with? Here, the work of Levin et al. (1998), Batabyal (1998), Walker (1998), and others tells us that the answer to the above question is an unambiguous "yes."[2]

Once we agree with the "yes" answer in the preceding paragraph, the question arises as to which definition of resilience—engineering or ecological—to use when studying socioeconomic systems. Unfortunately, the extant literature in regional science does not provide a clear answer. For instance, on the one hand, Stanickova and Melecky (2017) contend that for regional economic analysis, "the most natural conceptual meaning of economic resilience is the ability of a regional economy to maintain or return to a pre-existing state (typically assumed to be an equilibrium state) in the presence of some type of exogenous shock." The implication here is that engineering resilience is the appropriate notion to focus on. In contrast, in their discussion of how regional social-ecological systems ought to be managed, Lebel et al. (2006) note that "[t]he alternative to trying to maintain, or transform to, a system configuration that is very narrowly defined is to manage resilience. Resilience is a measure of the amount of change a system can undergo and still retain the same controls on structure and function or remain in the same domain of attraction. . . " These researchers are plainly talking about ecological resilience.

The fact that there is no one answer to the question of which definition of resilience to use when studying socioeconomic systems in regional science is not a problem. That said, researchers do need to comprehend the *criteria* that will help them decide whether their focus in any given instance ought to be on engineering or on ecological resilience. In the interest of generality, we now focus on an arbitrary socioeconomic system that is stochastic in nature—as all actual socioeconomic systems are—and show how a probabilistic framework can be utilized to meaningfully distinguish between the notions of Holling, or ecological and Pimm or engineering resilience. That said, we emphasize that this is one way- –and not the only way—to draw out the differences between these two concepts of resilience.

2.2. A Probabilistic Standpoint

Recall that a key aspect of Holling's (1973) definition of resilience is the focus on the capacity of a socioeconomic system to absorb disturbances and remain within the same basin of attraction. When resilience is looked at in this manner, the emphasis is *not* on the speed of return to an equilibrium but instead on the likelihood of our system *not* shifting to an alternate regime.

Let time be discrete and let the random state of our socioeconomic system at any time t be denoted by $X(t) \subset \mathbb{R}$. Suppose there exists a critical threshold $\mathcal{C}$ with the property that

$$X(t) \leq \mathcal{C} \Rightarrow \text{system in Regime A}, \tag{1}$$

[1]Such systems are said to be jointly determined because their evolution over time—and possibly space—is determined by forces that are partly ecological and partly economic in nature.

[2]In this regard, it should be noted that the analysis of socioeconomic systems is made complex by the interacting roles of the trinity of institutions, markets, and prices. This trinity and the associated behavioral responses have no obvious counterpart in purely ecological systems.

and

$$X(t) > \mathcal{C} \Rightarrow \text{system in Regime B}, \tag{2}$$

for dissimilar regimes A and B. Now suppose that at time t, a shock or disturbance $\mathcal{S}$ perturbs our socioeconomic system so that at time $t+1$ we have

$$X(t+1) = X(t) + \mathcal{S}, \tag{3}$$

where, mathematically, the shock $\mathcal{S}$ is a random variable with the cumulative distribution function $F_{\mathcal{S}}(s)$.

In the setting that we have just delineated, Holling or ecological resilience, denoted by R_H, can be thought of as the probability of staying in, for instance, regime A. Therefore, we can write

$$R_H = \text{Prob}\{X(t) + \mathcal{S} \leq \mathcal{C}\}. \tag{4}$$

If we denote the value of the state of our socioeconomic system at time t, before it is shocked, by x then we can, with more detail, define the Holling resilience of our socioeconomic system or R_H as

$$R_H = \text{Prob}\{\mathcal{S} \leq \mathcal{C} - x\} = F_{\mathcal{S}}(\mathcal{C} - x). \tag{5}$$

Note that this probabilistic definition of the Holling resilience of our socioeconomic system accounts for three salient points. First, the distance to the threshold is $\mathcal{C} - x$. Second, we are accounting for the distribution of shocks. Finally, we are explicitly focusing on our socioeconomic system's capacity to absorb shocks. If our socioeconomic system is far from the threshold, i.e., when $(\mathcal{C} - x)$ is large, this system will have high Holling resilience because the probability of crossing this boundary is small.

Let us now think in terms of the basin width aspect of Holling resilience. Suppose the above-mentioned shocks are such that we can write

$$X(t+1) = X(t) + \mathcal{E}(t) \tag{6}$$

where $\mathcal{E}(t)$ denotes independent and identically distributed (i.i.d) shocks. In this case, with a slight modification, the Holling resilience of our socioeconomic system becomes

$$R_H(t) = \text{Prob}\left\{\max_{1 \leq u \leq T} X(u) \leq \mathcal{C}\right\} \tag{7}$$

As written in equation (7), the Holling resilience of our socioeconomic system is the *survival probability* over the time horizon from 1 to T. Therefore, two points now follow. First, the Holling or ecological resilience is the *probability* that our socioeconomic system (stochastic process) never exits a given domain. Second, the Holling resilience of our socioeconomic system can be thought of as a first-passage time problem (Ross, 1996).

Very different from the concept of Holling resilience is the notion of engineering resilience discussed by Pimm (1984). In Pimm's interpretation, applied to a socioeconomic system, resilience is the speed with which this system returns to an equilibrium after it has been shocked or perturbed in some way. The focus now shifts from a survival probability to an expected recovery time. To see the Pimm (1984) notion in mathematical terms, consider a mean-reverting stochastic process that evolves over time in accordance with the law of motion

$$X(t+1) = \alpha X(t) + \epsilon(t), \tag{8}$$

where $\alpha \in (0,1)$ and $\epsilon(t)$ is mean-zero noise. Suppose this socioeconomic system is shocked at time $t = 0$. Then, the expected state of this system at time t is given by

$$\mathbb{E}[X(t)] = \alpha^t X(0), \tag{9}$$

where $\mathbb{E}[\cdot]$ is the expectation operator. In other words, we can say that this system converges geometrically to a (zero) equilibrium.

What about the expected recovery time? To shed light on this time, think of recovery as reaching a small neighborhood $\zeta > 0$. Then, using the notion of an infimum or greatest lower bound (Rudin, 1976), we can let τ be

$$\tau = \inf\{t : |X(t)| \leq \zeta\}. \tag{10}$$

With this definition in place, engineering resilience or R_P can be written as

$$R_P = \frac{1}{\mathbb{E}[\tau]}, \tag{11}$$

or, alternatively, looking at the rate parameter, we have

$$R_P = -\ln(\alpha). \tag{12}$$

Inspecting equation (12), the closer α is to 1, the slower is the convergence of the system under study, and the lower is the Pimm resilience of this system. Looked at in this way, Pimm resilience becomes either an expected hitting time problem (equation (11)) or the convergence rate in a stochastic difference equation (equation (12)).

Table 1 highlights the key differences between the notions of Holling and Pimm resilience from a probabilistic standpoint. What we learn from our probabilistic analysis is that regional scientists need to comprehend that the notion of resilience is fundamentally about the distributional properties of stochastic trajectories. Holling (1973) emphasizes tail risk and regime shift, whereas Pimm (1984) stresses the expected speed of convergence. Our probabilistic framing clarifies that these notions of resilience are not contradictory. They measure different aspects of stochastic stability: one about staying (Holling) and the other about returning (Pimm). We now proceed to discuss the second of our three foundational issues concerning the use of resilience in regional science. This issue involves shedding light on whether resilience is a process.

3. IS RESILIENCE A PROCESS?

Several researchers in regional science contend that resilience is a process. In this regard, the work of Martin and Sunley (2015) is representative. According to these researchers,

Table 1: Aspects of Holling and Pimm Resilience

Conceptual Differences Between Holling and Pimm Resilience		
Feature	Holling or Ecological Resilience	Pimm or Engineering Resilience
Key Question	Will System Stay in Basin?	How Fast Will System Return to Equilibrium?
Probability Object	Survival Probability	Expected Recovery Time
Mathematical Object	First-Passage Probability	Convergence Rate or Hitting Time
Key Parameter	Distance to Threshold	Speed of Mean Reversion

"resilience is a process that involves several elements. . . *vulnerability*. . . *shocks*. . . *resistance*. . . *robustness*. . . and *recoverability*." This contention notwithstanding, there is great disagreement more generally in the social sciences about whether resilience is a process.

For example, the psychologist and social scientist Ungar (2018) observes that "studies of social-ecological systems tend to see resilience as the capacity of a system, closer to the description of a trait than a process. . . " He (2018, p. 3) then says that "[p]sychologists, social workers, and other mental health professionals, on the other hand, abandoned descriptions of resilience as a trait decades ago and now describe resilience most often as a process." Finally, he (2018, p. 3) contends that this "difference between the disciplines has become somewhat blurred as social-ecological systems researchers. . . have shown interest in the structure and processes associated with nested adaptive cycles across scales."

Although Ungar (2018) and other researchers such as Rutter (1987) and Masten (2014) argue that resilience is a process, we contend that resilience is a characteristic of a socioeconomic system and *not* a process. To see why this claim makes sense, consider the following two points. First, we go back to the ecology literature, where the term resilience originated, and pay careful attention to what prominent ecologists have said about this concept. Two examples follow in the next paragraph.

C.S. Holling, who introduced the notion of resilience into the ecology literature in 1973, says in a more recent contribution (1996, p. 32) that the resilience "of a system has been defined in two different ways in the ecological literature. These differences in definition reflect which of two different aspects of stability are emphasized." Levin (2015, p. 1) says that ecological resilience is "the ability of an ecosystem to maintain its normal patterns of nutrient cycling and biomass production after being subjected to damage caused by an ecological disturbance." These two quotations from ecology tell us that resilience is a characteristic of a system and *not* a process.

Our second point concerns the need to distinguish between the characteristic of a socioeconomic system and intertemporal observations of this characteristic. Intertemporal observations clearly do constitute a process, but the observations themselves are about a characteristic, and this characteristic can be viewed at a point in time—in which case there is clearly no process—or over time—in which case we do have a process. To grasp the distinction we are making, consider the following regional and mathematical examples.

Consider the states of New York and Arizona in the United States that are clearly distinct regions. The topography and vegetation of these two regions differ sharply. New York's climate supports dense deciduous and mixed forests, maples and oaks, fertile valleys, and abundant freshwater wetlands. Arizona, by contrast, is dominated by arid plateaus and deserts.[3] Vegetation is sparse and drought-adapted—cacti, creosote bush, and mesquite—reflecting low rainfall and high temperatures, though pine forests appear at higher elevations. These topography and vegetation related differences are *characteristics* of these two regions, and they are *not* processes. However, when we look at one or more of these characteristics, such as the aridity of the land over time, we do get a process of observations about this characteristic. But it makes no sense to refer to the aridity of the land as a process.

To see this distinction mathematically, let us go back to our previous discussion of the differences between the twin notions of Holling and Pimm resilience in section 2.2. As before, let time be discrete and let the *random* state of a socioeconomic system at any time t be denoted by $X(t)$. The state of this system can refer to any one of several different attributes, but for concreteness, suppose state refers to the infant mortality in this system. Then, if we say that at time $t+1$, $X(t+1) = \bar{x}$, then what we are saying is that the magnitude of infant mortality in this socioeconomic system at time $t+1$ is equal to $\bar{x}$. In other words, infant mortality is a characteristic of this socioeconomic system and not a process. That said, if we observe infant mortality in this socioeconomic system over time $t, t+1, t+2$, etc., then we do get a sequence of observations that would constitute a process, but this process is about how a characteristic, i.e., infant mortality, changes over time. We now discuss whether resilience is always a *good thing* that decision-makers ought to promote.

4. IS RESILIENCE ALWAYS A GOOD THING?

4.1. Two Interrelated Queries

Recall that Holling's resilience is defined to be the capacity of a socioeconomic system to absorb disturbances and still retain its basic structure and function. While analytically powerful, this definition is normatively neutral: a system can be highly resilient and yet be socially undesirable. Organized crime networks, corrupt political machines, exclusionary land-use regimes, or carbon-intensive energy systems can all display remarkable resilience by continuing in the face of reform efforts, economic shocks, or environmental pressures. In such cases, resilience means entrenchment. Therefore, promoting resilience without specifying the normative status of the socioeconomic system risks stabilizing poverty traps, ecological degradation, or authoritarian governance. The fact that a configuration is stable and difficult to dislodge does not make it worthy of preservation (Perrings, 1998).

For this reason, policymakers must always ask, "Resilience of what?" and "Resilience for whom?" A regional economy may be resilient in maintaining employment in declining fossil-fuel industries, yet that same resilience may delay decarbonization and undermine long-term welfare. Similarly, a socioeconomic system may be resilient in a high-unemployment

[3]Go to https://bplant.org/region/1376 and https://www.britannica.com/place/Arizona-state for additional details. Accessed on 10 March 2026.

state that provides few job prospects for citizens living in this system. By foregrounding the object and beneficiaries of resilience, policymakers are forced to confront distributional consequences and ethical trade-offs. The aim should not be resilience *per se*, but the resilience of systems that advance equity, sustainability, and well-being. Without this specification, resilience becomes an empty virtue—capable of justifying the preservation of precisely those structures that ought to be transformed. As in section 2.2, we now focus on an arbitrary and stochastic socioeconomic system and show how a probabilistic framework can be used to comprehend the point that resilience is not always a good thing that must be enhanced.

4.2. A Probabilistic Viewpoint

Consider a stochastic socioeconomic system that can exist in one of two possible states: on or off. These two states can represent periods in which some desirable socioeconomic activity is happening versus periods in which this same activity is either interrupted or inactive. Here are two examples. First, consider employment cycles in our system's labor market. In this case, the system being on refers to the length of time during which unemployment is below some acceptable threshold, and the same system being off refers to the length of time during which unemployment is above this same threshold. As a second example, consider the availability of a service such as electricity or water supply or public transit, in which case the system is on. When any one of these three services is unavailable, the system is off.

Suppose that initially, our system is on and that it remains on for a random amount of time Z_1. It then goes off for a random amount of time Y_1. The system then goes on again for a random amount of time Z_2 and then goes off again for a random amount of time Y_2 and so on and so forth. We suppose that the random vectors (Z_n, Y_n), $n \geq 1$, are independent and identically distributed. Hence, both the sequence of random variables $\{Z_n\}$ and $\{Y_n\}$ are independent and identically distributed, but Z_n and Y_n may depend on each other. What this means is that each time our socioeconomic system goes on, everything starts again, but when it goes off, then we permit the length of the off time to depend on the previous on time. Finally, let $H(\cdot)$ be the cumulative distribution function of Z_n, $G(\cdot)$ be the cumulative distribution function of Y_n, and $F(\cdot)$ be the cumulative distribution function of $Z_n + Y_n$, $n \geq 1$.

Let us define the length of a cycle to be X_n, where $n \geq 1$. Then, it follows that $X_n = Z_n + Y_n$, $n \geq 1$. The successive cycle completion times constitute a renewal process (Ross 1996, pp. 109–123) that we can express as $S_n = \sum_{i=1}^{n} X_i$ and the system is on in cycle n during the interval $(S_{n-1}, S_{n-1} + Z_n)$. With this background in place, we now want to compute the Holling resilience of this system at any time t or $R_H^g = P(t) = \text{Prob}\{\text{system is on at time } t\}$.

Our system is on at time t if for some $n \geq 1$,

$$S_{n-1} \leq t < S_{n-1} + Z_n. \tag{13}$$

Let us now condition on the time $u = S_{n-1}$ when the nth cycle begins. Then,

$$\text{Prob}\{u \leq t < u + Z_n\} = \text{Prob}\{Z_n > t - u\} = 1 - H(t - u). \tag{14}$$

If we let $m(t)$ denote the renewal function—see Ross (1996, p. 99)—which tells us the expected number of completed cycles by time, t and we let $dm(u)$ be the associated renewal measure, then we want to sum over all possible cycle start times. Doing this, we get the Holling resilience of our socioeconomic system at any time t or R_H^g. The expression we seek is

$$R_H^g = P(t) = \{1 - H(t)\} + \int_0^t \{1 - H(t-u)\} dm(u). \tag{15}$$

If we wanted to find the long-run or steady-state Holling resilience of our socioeconomic system $R_H^{g,\infty}$ or the expression $\lim_{t\to\infty} P(t)$, then we can do so by using Theorem 3.4.4 in Ross (1996, p. 115). Using this theorem, we get

$$R_H^{g,\infty} = \lim_{t\to\infty} P(t) = \frac{\mathbb{E}[Z_n]}{\mathbb{E}[Z_n] + \mathbb{E}[Y_n]}. \tag{16}$$

Note well that the Holling resilience given in equations (15) and (16) describes the resilience of a *good thing*, i.e., the Holling resilience of our socioeconomic system when it is on, either in the short-run (equation (15)) or in the long-run (equation (16)). This is why we have the superscript g in equations (15) and (16). Let us now compare this measure of our system's Holling resilience with the corresponding Holling resilience of a bad thing, i.e., when our socioeconomic system is off. In symbols, we want to compute $R_H^b = P(t) = \text{Prob}\{\text{system is off at time } t\}$.

Using the methodology employed above, it can be shown that the probability we now seek at any time t is given by

$$R_H^b = P(t) = H(t) - \int_0^t \{1 - H(t-u)\} dm(u). \tag{17}$$

Similarly, using Theorem 3.4.4 in Ross (1996, p. 115), we can compute the long-run or stationary Holling resilience of our socioeconomic system or $R_H^{b,\infty} = P(t) = \Pr\{\text{system is off at time } t\}$.
We get

$$R_H^{b,\infty} = \lim_{t\to\infty} P(t) = \frac{\mathbb{E}[Y_n]}{\mathbb{E}[Z_n] + \mathbb{E}[Y_n]}. \tag{18}$$

Equations (17) and (18) give us the resilience of our socioeconomic system when it is off. In other words, we now have the resilience of a *bad thing*.

Equations (15) versus (17) and equations (16) versus (18) describe the essence of our central argument in this section. From a short-run perspective, equation (15) describes the Holling resilience of a good thing (socioeconomic system is on), and equation (17) also describes the Holling resilience of the same socioeconomic system, but when it is off, which is a bad thing. The same interpretations apply to the two long-run measures of Holling resilience in equations (16) and (18). From a decision-making standpoint, it makes sense to want to put policy measures in place so that the Holling resilience in either equations (15) or (16) is *maximized*. On the other hand, it makes sense to take steps to *minimize* the Holling resilience of our socioeconomic system described in equations (17) or (18).

Given this discussion, it should be clear to the reader that the answer to the question in the title of this section is “no” and resilience is not always a good thing. In other words, as the ecologist Simon Levin and his colleagues (1998, p. 226) have pointed out, “[n]ot all resilient phenomena are desirable. For example, discriminatory class systems have proved resilient. Similarly, racism has proved stubbornly resistant to policies aimed at wrecking its foundations.” We now proceed to the second and final objective in this paper. Specifically, we provide a detailed discussion of the connections between the twin notions of resilience and sustainability.

5. RESILIENCE VERSUS SUSTAINABILITY

5.1. Basic Differences

As we have seen in the discussion thus far, Holling or ecological resilience refers to the capacity of a socioeconomic system to absorb disturbances and still retain its basic structure and functions. In this perspective, resilience is about the ability of a system to remain within a given regime despite shocks such as environmental change, economic disruptions, or social stresses (Mayar et al., 2022). A key implication of this idea is that resilience is largely state-neutral: a socioeconomic system can be highly resilient even if the state in which it persists is *undesirable*. For example, a persistent poverty trap or a dysfunctional institutional arrangement can both be resilient if they are able to withstand disturbances and continue operating in essentially the same way (Levin et al., 1998).

In contrast, sustainability refers to the ability of a socioeconomic system to maintain desirable conditions or outcomes over long periods of time. The concept is inherently normative because it involves judgments about which outcomes ought to be preserved, such as environmental quality, resource availability, or human well-being (Renn et al., 2009). Unlike the notion of Holling resilience, sustainability therefore asks whether the long-run trajectory of a socioeconomic system remains within a set of acceptable or beneficial states. This distinction implies that resilience and sustainability are *not* identical (Batabyal, 2024). A socioeconomic system may be resilient but unsustainable if it continually maintains harmful conditions, and conversely, achieving sustainability may sometimes require reducing the resilience of undesirable regimes so that a transformation towards more desirable states becomes possible. We now use elementary probability theory to illustrate how the differences between Holling's resilience and sustainability can be understood.

5.2. A Stochastic Perspective

Probability theory offers a simple way to clarify the conceptual difference between Holling resilience and sustainability by focusing on how a socioeconomic system behaves in the presence of random disturbances. Let a socioeconomic system have a state variable $X(t)$ that evolves over time as a stochastic process. Suppose there exists a desirable set of states $\mathcal{S}$ (economy of our system with acceptable welfare provisions). In this probabilistic setting and consistent with our previous discussion in this paper, the Holling resilience of our system is the *likelihood* that this system remains within, or returns to, the desirable set after one or more shocks or disturbances.

Since these shocks typically occur randomly, one way to capture the notion of Holling resilience R_H is to say that it can be described by the probability

$$R_H = \text{Prob}\{\tau < \infty\} \tag{19}$$

that our system returns to the set $\mathcal{S}$ after leaving it and τ is the first return time. A highly Holling resilient socioeconomic system is one for which the probability in equation (19) is large, meaning that even if disturbances push the system away from desirable conditions, there is a high probability that the underlying dynamics bring it back. Thus, as we have noted elsewhere in this paper, Holling resilience emphasizes the recovery and the continuity of a regime despite the occurrence of stochastic shocks.

In contrast, one way to represent the notion of sustainability is to say that it focuses on the *long-run* probability that the system remains within acceptable bounds over time. Using the same stochastic process $X(t)$, the notion of sustainability or $\mathbb{S}$ can be described by the probability

$$\mathbb{S} = \text{Prob}\{X(t) \in \mathcal{S} \ \forall t \geq 0\}, \tag{20}$$

or by the long-run fraction of time that the socioeconomic system spends in the set $\mathcal{S}$. A sustainable system is therefore one in which the probability of remaining in the set of desirable states over the long run is high. Unlike Holling resilience, which emphasizes the ability to recover after leaving $\mathcal{S}$, sustainability emphasizes maintaining desirable conditions continuously over time.

In probabilistic terms, the key difference between the two concepts is that Holling resilience is about recovery probabilities after one or more disturbances, whereas sustainability is about the long-run probability of staying within acceptable states. In this way of looking at resilience and sustainability, a socioeconomic system can be resilient but not sustainable if, for example, it frequently collapses but reliably recovers, or sustainable but not highly resilient if it rarely leaves the desirable state but, once displaced, has a low probability of returning to this set.

We close this section by pointing the reader to two salient conclusions that emanate collectively from the various papers published in a special issue of the journal *Environment and Development Economics* in 2006 and that regional scientists ought be aware of when analyzing socioeconomic systems and specifically when exploring the links between resilience and sustainable development. First, for socioeconomic systems, markets may be *missing* for characteristics of the system that may affect its resilience and possibly its sustainability. In such situations, prices can lead decision-makers to take actions that push the system closer to unseen *thresholds*. Second, using the lens of modern finance, sustainable development requires that the value of the *asset* base available to a population not decline over time. In this regard, a resilience perspective implies that the *composition* of this asset base is very important. This concludes our discussion of some contested issues in connection with the use of resilience in regional science.

6. CONCLUSIONS

In this paper, we used elementary probability theory to provide a thorough analysis of three foundational issues and one policy-related issue associated with the use of resilience in regional science. The foundational issues addressed questions of definition, whether resilience ought to be understood as a process or as the characteristic of a socioeconomic system, and whether such a system's resilience ought to be regarded as inherently desirable and therefore something to be promoted. The policy-related issue concerned the relationship between the two concepts of resilience and sustainability.

The analysis in this paper can be extended in several different directions. Here are two examples of potential extensions. First, it would be useful to conduct research to determine useful ways in which the probabilistic and yet scalar measures of resilience discussed in this paper might be operationalized to provide numerical guidelines to policymakers looking to enhance the resilience of the good states of actual socioeconomic systems. Second, research that focuses on how to construct multidimensional measures of resilience that simultaneously focus on many desirable features of a socioeconomic system ought to assist policymakers in managing such systems more efficaciously.

Finally, understanding C.S. Holling's notion of resilience in particular can help policymakers better manage socioeconomic systems by shifting attention from maintaining a single "optimal" equilibrium to preserving the capacity of systems to absorb shocks and continue functioning. As we have seen, Holling resilience refers to the size of the disturbance a system can absorb before it shifts into a different regime. When applied to economies, cities, or regional systems, this perspective encourages managers to focus on diversity, redundancy, and adaptive capacity rather than on rigid efficiency.

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