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Economic Vulnerability and Resilience to Natural Hazards: A Survey of Concepts and Measurements

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Abstract: With the shift from a hazard-centered disaster paradigm to one that places emphasis on vulnerability and resilience, disasters triggered by natural hazards have begun to be perceived as unnatural occurrences. To date, the theoretical conceptualization and empirical measures of vulnerability and resilience remain subjects of contentions. This survey of the empirical economic literature aims to describe the progress made in the conceptualization and measurement of the economic dimensions of vulnerability and resilience in the context of natural hazards, and to provide useful insights for policy-making. Economic vulnerability and economic resilience, interacting with the hazard itself, and the exposure of populations and physical assets, are considered to be critical determinants of the resulting impacts of disasters. The empirical evidence provides systematic support for the hypothesis that apart from the characteristics of the hazards, the potential for people and economies to avoid adverse impacts and their capacity to withstand and rebound from a disaster are influenced by a confluence of socio-economic factors.

1. Introduction

Decades ago, the discourse on disasters was largely about natural hazards and their characteristics. Disasters were viewed as products of processes of the geophysical world [1]. Thus, governments' interventions were mainly structural, such as hazard protection measures such as flood defenses [2]. This paradigm was eventually seen to have failed to tackle the conditions that resulted in varying impacts of hazards on people [3]. Over time, and particularly with the experiences of developing countries, the concept of vulnerability emerged in the disaster discourse. Disasters triggered by natural hazards have since been widely viewed as unnatural occurrences that are brought about by a confluence of societal factors along with these natural hazards [2]. This view, that disasters were the result of the interaction between natural hazards and societal factors, appeared as early as in the 1970s (see Kates [4], and O'Keefe, et al. [5]), but this view did not readily gain wide acceptance at that time.

Consequent to this paradigm shift is the heightened interest by a multiplicity of disciplines in gaining a deeper understanding of the important underlying factors that allow hazards to become disasters. From this increasing understanding of vulnerability, emerged a likewise increasing appreciation of the distinct role of resilience in shaping the consequences that follow from the resulting disasters impacts.

There is a large volume of conceptual and empirical literature on vulnerability and resilience to natural hazards. While majority of these works are from diverse social sciences, the economic dimension of vulnerability and of resilience is typically covered. Researchers within economics started later, particularly around the year 2000, though the pioneering works on the economics of disasters came much earlier through the works of Dacy and Kunreuther [6] and Albala-Bertrand [7]. Dacy and

Kunreuther [6] examined the determinants of long-run recovery, including infrastructure networks, insurance, and public policy. Meanwhile, Albala-Bertrand [7] developed a framework for the analysis of disasters in developing countries, and argues that while development influences the occurrence of a disaster, disasters are not obstacles towards development.

Economic vulnerability and economic resilience, interacting with the hazard itself and the exposure of populations and physical assets, are considered to be critical determinants of the resulting disaster damages and losses. Indeed, disasters are largely influenced by economic forces, so that "the very occurrence of disasters is an economic event" [8].

This work aims to describe the progress made in the conceptualization, and the measurement of the economic dimensions of vulnerability and resilience in the context of natural hazards. We present selected definitions and frameworks that capture some, but not all, of the views of the different communities or disciplines involved in the natural hazard discourse. There is a myriad of work that adopts various methodological approaches inside and outside the Economics discipline. We do not fully cover this diversity in our survey. One of the more prominent of these is the complex adaptive systems methodology, which provides an understanding of the cumulative impacts of natural hazards by taking an evolutionary approach [9]. Other useful approaches are the general equilibrium methods and the partial equilibrium analysis. We present and synthesize the findings from econometric studies to provide broad insights for policy decision-making. Given this specific contextual backdrop, we start with the four-component disaster risk formulation as follows:

$$Disaster\ Risk = f\ (Hazard,\ Exposure,\ Vulnerability,\ Capacity).$$

This formulation was adopted by the United Nations General Assembly as part of the global attempt to develop assessment indicators for the Sendai Framework for Disaster Risk Reduction 2015–2030; these aim to be the targets that are coherent with the indicators for the Sustainable Development Goals [10]. Here, Disaster Risk is defined as "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society, or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity." Hazard is "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation." Exposure is "the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas." Vulnerability refers to "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." Finally, Capacity is "the combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risk and strengthen resilience" [10]. We adopt the broad term "Capacity" here to cover both "adaptive capacity", as defined by the IPCC [11], and "coping capacity" as defined by the UN [10] and the UNISDR [12].

Resilience refers to "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures, and functions through risk management" [10].

This work is organized as follows: Section 2 provides highlights on selected perspectives and conceptualization on vulnerability and resilience across different disciplinary approaches. It then focuses the discussion on economic vulnerability and economic resilience in broad terms, and subsequently, in the specific context of the natural hazard discourse. Section 3 presents a selection of empirical works on the determinants of economic vulnerability and economic resilience in using indices and econometric approaches. Section 4 provides a synthesis and implication for policy, including areas that need further research and refinement.

2. Definitions and Frameworks on Vulnerability and Resilience

A number of comprehensive reviews (e.g., Birkmann [13], Gaillard [14], Thywissen [15], and Villagran de Leon [16]) reveal the distinct conceptualization of vulnerability and resilience in each of the disciplines and communities involved in the natural hazards discourse.

The multiplicity of separate efforts has led to differences in understanding, if not confusion, about these concepts [17]. This is not surprising, as each discipline is likely to maintain its specific definitions and disciplinary frameworks when examining natural hazards and disasters, without making the adjustments and contextualizations to align with other disciplines. Apart from the separate efforts of the various academic disciplines (e.g., sociology, geography, economics, planning, or public health), the definitions and frameworks continue to evolve by their usage within the disaster risk reduction (DRR) community, and the climate change community.

Prior to the four-component disaster risk formulation presented in Section 1, the most popular and longest standing disaster risk formulation by the disaster risk community has been as follows: *Risk = Hazard × Exposure × Vulnerability*. This was presented by the United Nations Disaster Relief Co-ordinator in 1979 as contained in the Report of Expert Group Meeting [18] and later contained in their disaster risk training modules.

The two-component risk formulation, i.e., *Risk = Hazard × Vulnerability*, is another early variant. It captures the two opposing components under the Pressure and Release (PAR) framework [1,3]. Focusing on people, vulnerability is defined in this framework as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard" [1]. In this conceptualization, it is evident that vulnerability encompasses exposure. Worthy of note is that this definition captures what generally are considered to be the components of resilience, as defined by UNISDR [12] and UN [10]. However, despite this definition, the framework traces the channels through which a disaster occurs when a natural hazard affects the vulnerable.

The Progression of Vulnerability Framework [19] further elaborates this PAR framework. This framework distinguishes among three levels of progression of vulnerability: "Root causes" include the economic and social structures that influence how resources, wealth, and power are distributed, the ideologies in governance, and the history and culture. "Dynamic pressures" are grouped into the deficiencies of society's economic, social, and political processes, and macro-forces, such as rapid population growth and rapid urbanization, deforestation, decline in soil productivity, among others. These serve as the channels through which the root causes result in fragile livelihoods in unsafe locations, which is the final level in the progression [1,19]. Apart from that, in the PAR, there are a number of other earlier definitions of vulnerability that subsume either or both exposure and resilience. For instance, Pelling [20] identifies three components of vulnerability: exposure, resistance (i.e., the capacity to withstand adverse impact), and resilience (i.e., the capacities to cope and adapt).

In the second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), vulnerability is presented as a function of sensitivity, exposure, and adaptive capacity [21]. It groups the negative and positive factors that determine vulnerability, into two separate components, namely, sensitivity and resilience. In its third Assessment Report, the IPCC presented the view that resilience is the "flipside of vulnerability" [22]. At the time that these reports were released, the climate change community and the DRR community each adopted a framework that is lacking in commonality, even though these communities tackle some common hazards.

A major development in this conceptualization was contained in the IPCC's Fifth Assessment Report [11]. It is the adoption of a risk framework that mirrors the three components of the DRR community's Hazard/Exposure/Vulnerability risk equation. In this framework, the IPCC refers to vulnerability as the "propensity or predisposition to be adversely affected" [11], which basically captures only the "sensitivity" component of its earlier vulnerability definition, and which is consistent with the UNISDR [12] definition. This harmonization by these two key institutions (UNISDR working on DRR and the IPCC on climate change) can be considered to be a major step towards achieving greater synchronization of efforts between these two communities.

Meanwhile, the evolution of the concept of resilience in the context of natural hazards dates about as far back as that of vulnerability, though, as previously noted, it has been typically subsumed either under vulnerability or other components of risk. In tracing how the term "resilience" came to be used in DRR, Alexander [23] identifies the term's Latin origin. Though a myriad of DRR literature declares Holling [24] as the first to coin the term, the work of Bacon in 1625 is the first known scientific use of the term in its present form, in the English language [23]. Holling [24] described resilience to shocks in the context of ecological systems. He refers to resilience as a system's ability to absorb changes and to persist amidst these changes. Meanwhile, in the geosciences disciplines, the concept is interpreted as the ability to withstand the occurrence of the hazard, while incurring only tolerable levels of losses [25].

Engineering puts particular attention on the amount of time it takes to recover from the adverse impact of a shock [26]. From an ecological perspective, Pimm [27] presents a similar definition to that in Engineering by referring to resilience as the speed of recovery following a disturbance. Apart from speed of recovery, which he refers to as rapidity, Bruneau, et al. [28] posits that robustness, redundancy, and resourcefulness also determines the resilience of physical and social systems. These reduce the chances of experiencing shocks, and, in the event that a shock occurs, the affected systems are readily able to absorb it with minimum adverse effects. As a result of this increasing appreciation of the distinct influence of resilience on disaster risk, there are now disaster risk frameworks that include resilience as an additional component of disaster risk (as in Hallegatte [29] and Rose [30].

In Economics, the concept of vulnerability is typically applied to four areas of interest, other than disasters: poverty, food security, asset-vulnerability, and sustainable development [31,32]. Most often, vulnerability is analyzed in the study of the dynamics of poverty, focusing on the "risk of falling into poverty or deeper into poverty" (Moret, 2014). Likewise, resilience is used in three research strands: economic shocks, sustainability, and institutions [30].

Briguglio and colleagues [33–35] are among the first to simultaneously study economic vulnerability and economic resilience, and to posit that these two jointly determine a country's risk of being affected by external shocks. Specifically, they refer to economic vulnerability as a country's exposure to external shocks due to its inherent economic characteristics—the economic openness, export concentration, and the dependence on strategic imports of the country in question. These are conceived as structural, and therefore difficult to change with deliberate policies (at least in the short-term). On the other hand, economic resilience refers to the economy's coping ability that can, in contrast, be influenced by policies [34]. Policies that induce and nurture resilience are those that enhance macroeconomic stability, increase market efficiency, improve governance, and expand social development.

Rose [30], in his review of the economic literature, finds that several important dimensions of economic resilience are not given adequate emphasis in this literature, and that some are not considered at all in the existing conceptualizations. He argues that, above all, there is a need to distinguish between damages to stocks (i.e., property damage), and damages to flows (i.e., damages to production of goods and services). While damages to stocks are incurred all at once at the time of the shock, the damages to flows, however, also start immediately with the hazard occurring, but continue to be incurred until full recovery is achieved. Thus, Rose [30] argues that damages to flows are more relevant to the economic resilience concern.

The Damage and Loss Assessment (DALA) methodology introduced by the United Nations-Economic Commission for Latin America and the Caribbean (UN-ECLAC) in 1972 [36] and widely used among the Development multilaterals (such as the World Bank), also adopts a stock-flow typology of disaster impacts [37]. In this ECLAC methodology, *direct damages* refer to the damages to the *stock* of assets that are incurred at the time of the disaster and immediately after, while *indirect loss* refers to the reduction in the economic *flows* due the decrease in the production of goods and services, and other macroeconomic effects [37]. Rose [38] argues that the use of 'direct' and 'indirect' labels to refer to stocks and flows impacts is misleading, since the impacts on flows begins at the time when the disaster occurs. Moreover, he argues that both impacts to stocks and flows have corresponding

direct and indirect effects. This stock-flow and direct-indirect typology proposed by Rose [38] has been adopted in various US National Academy of Sciences reports (NRC [39–41]), and in the economic assessment of disaster consequences, as in NMC [42].

Rose [43] defines economic resilience as "The process by which a community develops and efficiently implements its capacity to absorb an initial shock through mitigation and to respond and adapt afterward so as to maintain function and hasten recovery, as well as to be in a better position to reduce losses from future disasters." In terms of interventions, Rose [43] states that preventative actions or mitigation measures reduce the magnitude of the hazard and/or the probability of a disaster to occur, as well as reducing vulnerability. Further, he argues that in the absence of mitigation and prevention measures, disaster impacts can be reduced through resilience, particularly through ingenuity, resourcefulness, and speedy repair and reconstruction both during and in the aftermath of a disaster occurrence [38,43].

Hallegatte [29] proposes an economic framework to guide the assessment of economic resilience. In his framework, resilience refers to the economy's ability to minimize people's welfare losses from a disaster, and the direct damages to assets do not fully capture the adverse impacts on people's welfare. Any systematic assessment of welfare losses requires the conduct of economic assessment of the losses of economic flows [44]. These asset losses lead to consequent losses of output, income, and consumption, which, together with asset losses, better captures the welfare losses resulting from a disaster. In this framework, asset losses and output losses are alternative typologies of economic costs resulting from a disaster that are, to an extent, distinct from the usual *direct damage* and *indirect loss* typology used by the ECLAC. Specifically, asset losses here refer to the reduction in the value of the *stock* of assets, while output losses refer to the reduction in the income *flow* [29]. Thus, this typology for economic costs is consistent with the damages to the stocks and flows of [43], rather than with the direct damage and indirect loss typology of the ECLAC framework.

This framework of Hallegatte [29] extends the risk equation into an "economic welfare disaster risk" with economic resilience as the fourth component, along with hazard, exposure and vulnerability. On the one hand, resilience at the macro-level is determined by the economy's ability to limit the immediate losses in income resulting from losses in assets (or the economy's instantaneous resilience), and by the economy's ability to "reconstruct and recover quickly" (referred to as dynamic resilience, as in [43]) [29,43]. On the other hand, resilience at the micro-level is influenced by the distribution of the losses incurred across the affected households, the household's ability to smooth their consumption, and their access to risk sharing schemes [29]. This framework can be a useful framework for practical application as it captures both the macroeconomic and microeconomic aspects of resilience. It is noted that a vast majority of the work at the "macroeconomic level and omits important consideration at the micro-level" [45].

Another principal contribution of the framework is that it takes into account socioeconomic heterogeneity, in order to measure the disparity in welfare losses, with a specific focus on losses for the poor. The framework further traces the channels through which asset losses lead to welfare losses. The methodologies and economic models in this framework are translated into a set of algorithms and processes that capture these channels. Hallegatte [29] identifies a corresponding list of indicators as "a first step toward the construction of a meaningful and measurable indicator for economic resilience". Using this framework, he proposes two approaches to reduce 'economic disaster welfare risk.' The first approach is to reduce the direct impacts of disasters on assets, and the second approach is to reduce the output losses resulting from the asset losses. The latter entails increasing the resilience of socio-economic systems, both at the macro- and micro-levels.

3. Assessment of Economic Vulnerability and Economic Resilience

Amidst the continuing evolution of the concepts, efforts have been made to translate these conceptual approaches into practical tools to empirically identify the determinants of the various dimensions of economic vulnerability and resilience.

a.   Indices of Vulnerability and Resilience

One of most commonly used methods to assess vulnerability and resilience to natural hazards is the index method. These indices aim to capture the multi-dimensionality of vulnerability and resilience, and therefore include their economic dimensions. The most common economic variables included are on output (gross domestic product (GDP) or regional production), income, employment, inflation, consumption, expenditures, savings, domestic and international financial transfers, public finance, and trade [16,46,47].

These indices vary in terms of purpose (e.g., assessment of vulnerability and/or resilience), spatial coverage (e.g., global, regional, local), scale of analysis (e.g., governments, local authorities, firm-level, household), and methodological approach (e.g., deductive, inductive, econometric). A majority of these indices employ an inductive approach, and the identification of indicators are based on relevant conceptual frameworks and/or on identified important indicators in the earlier empirical literature. The aggregation of indicators into a composite index is commonly done through ad-hoc arithmetic or geometric averaging, and standardization is typically done prior to aggregation. Where weights are applied, these are often based on expert judgment, or by participatory approaches, or a combination of both.

A more systematic method to identify relevant variables and to assign weights involves econometric algorithms, including data reduction methods such as principal component analysis (PCA) and factor analysis (FA). The social vulnerability index (SoVI) of Cutter et al. [48] is one of the earliest indices employing the PCA. The SoVI and its descendants is often used in sectoral level studies.

In the next two sub-sections, we present two global indices. The objective here is to show how indices based on related frameworks can be designed for a different purpose and to employ different approaches.

3.1. The Disaster Risk Index

The Disaster risk index (or the DRI) is the first index that employs a statistical approach that attempts to demonstrate the manner in which development affects human vulnerability and disaster risk [49,50]. The DRI is global in its coverage, and has a country-level scale of analysis. It is noted that the DRI was commissioned by the United Nations Development Program to be used to guide decisions by international and national policy-makers [51,52]. The DRI employs a deductive approach to identify different economic, social, and environmental indicators, which are then examined for their correlation with disaster deaths [49]. The DRI equation mirrors the standard risk equation: $R = H \times Pop \times Vu$; where *R* is disaster risk, measured in terms of number of deaths, *H* is the proxy for hazard, measured in terms of frequency of occurrence, *Pop* is the number of people living in the area exposed to the hazard, and *Vul* is vulnerability. Vulnerability is considered as the component of risk that explains why people with the same level of exposure face varying levels of risk [50]. As noted, the DRI uses only data on deaths to proxy for risk.

A total of 32 socio-economic and environmental variables were tested as potential important vulnerability factors for each hazard type [51]. The final set of vulnerability variables varies across hazards, depending on the results of separate regression specifications. Among the economic variables found to be important are the GDP per capita for tropical cyclones, droughts and floods, and urban growth for earthquakes. The results indicate that indeed, development influences the vulnerability to natural hazards, but the aspects of development that affect each hazard vary. Vulnerability to hydro-meteorological hazards, for example, is influenced by the level of development as measured by per capita GDP, while vulnerability to earthquakes is influenced by the process of development (in this case, urban population growth). A multiple-hazard composite index is constructed using the estimated risk for each hazard. A final output of the process is a risk map, where the countries covered are depicted in seven DRI classes/categories.

3.2. InFORM

The index for risk management (InFORM) is designed for a global analysis of humanitarian risk, and its target users are humanitarian organizations, donor agencies, country governments, and development stakeholders that have resilience as their key agenda [53]. The InFORM considers the four components in the UN [10] definition of risk, though risk here is not "probabilistically determined" [10]. Like the DRI, the InFORM takes a multiple hazards approach. However, unlike the DRI, which covers only natural hazards, InFORM covers human-made hazards as well. While the DRI employs a deductive approach in indicator selection, the InFORM employs an inductive approach. The InFORM is a composite index of over 50 indicators that are categorized and computed as follows:

$$Risk = Hazard\ \&\ Exposure^{\frac{1}{3}}\ \times\ Vulnerability^{\frac{1}{3}}\ \times\ Lack\ of\ coping\ capacity\ ^{\frac{1}{3}}$$

Consistent with the UNISDR [12], as well as in the UN [10], the InFORM defines vulnerability as people's susceptibility to hazards, and in the construction of the index, it is represented in two categories: socio-economic vulnerability and vulnerable groups [54].

Economic vulnerability is captured under the socio-economic category, which is computed as the arithmetic mean of indicators measuring development and deprivation, inequality, and aid dependency. We note that resilience is captured, though not in its entirety, under lack of coping capacity, which refers to the available resources that help people to "absorb the shock" [54]. For this component, governance, institutional, and infrastructure indicators (including access to health systems) are used.

We emphasize that while both indices presented above are at the macro-level, there are also micro-level indices that are designed to assess the economic vulnerability or resilience at the household or firm levels. Some useful reviews of the macro- and micro-level indices can be found in Cutter, et al. [47,55], and Rose and Krausmann [45].

b.   Econometric Approach: Determinants and Measures of Economic Vulnerability

Within Economics, econometric methods using cross-section or panel data approaches are the most commonly used to systematically identify the underlying factors that influence vulnerability and resilience. Econometric methods are mainly deductive, an approach which Pelling [49] asserts provide more realism than an inductive approach. Studies on the economics of disasters using these methods belong to two strands.

The first strand seeks to identify the factors that affect the disaster impacts on people and assets. These models generally take the following form:

$$Y_{it} = \alpha_0 + \beta_1 H_{it} + \beta_2 E_{it} + \beta_2 X_{it} + \varepsilon_{it};$$

where Y_{it} is the measure of actual impacts either on people or on assets in spatial unit i at time t; H_{it} is a vector of hazard characteristics; E_{it} is a measure of the exposure of people or assets; X_{it} is the vector of the characteristics of the exposed elements, including the social, economic, and physical environs. By controlling for hazard characteristics and the exposure of people and assets, these empirical models generate insights on the factors underlying the vulnerabilities of the exposed.

The second strand aims to measure the economic impacts typically in either the short-run (months to several years) or long-run (at least 3–5 years). These studies also attempt to understand the factors that influence these impacts, thereby also providing insights into the determinants of economic resilience. As surveyed by Cavallo and Noy [8], these models generally take the following form: $Y_{it} = \alpha + \beta X_{it} + \gamma\ DIS_{it} + \varepsilon_{it}$; where Y_{it} is the impact on economic flows for a spatial unit i at time t. These impacts are measured in terms of GDP (or growth), GDP per capita, human development index, and poverty and employment, among others. DIS_{it} is the immediate disaster impact to assets and/or to population. In some studies, this includes the hazard characteristics. X_{it} is the vector of control variables affecting Y_{it} [8].

As previously argued, resilience can refer to the ability to minimize welfare losses [29]. For this purpose, there is a need to decide on the appropriate measures of welfare to use. Indicators of production and outputs, such as GDP and its variants, are commonly used as a proxy for welfare, though consumption is arguably a better proxy [56]. There is a large economic literature that discusses the various measures of welfare. Nordhaus and Tobin [57] present one of the earlier arguments on the limitations of production and growth indicators as measures of welfare. In general, production only indicates how much is made available, while consumption indicates how much is actually used (consumed). It therefore better captures the economic concepts of utility and the standard of living. From a Utilitarist perspective, consumption is what matters most, and not output and production [44].

3.3. Determinants of Economic Vulnerability

While the DRI uses a cross-sectional dataset, the subsequent cross-country econometric empirical works use panel datasets, with the disaster impact data coming mainly from EM-DAT (other available databases include DesInventar, compiled by UNISDR, and privately held datasets collected by two re-insurance companies, MunichRe and SwissRe). Toya and Skidmore [58] and Raschky [59] examined the correlation between several aspects of development. Toya and Skidmore [58] assessed the extent at which disaster fatalities and losses decline as economies grow. Raschky [59] examined the important influence that institutions have on the vulnerability of people and assets to disasters. Their respective models took on a relatively simple form, as they did not have proxies for the characteristics of the hazards studied.

Many of the succeeding studies address the exogeneity concerns pointed out by Noy [60], by integrating into their model indicators on hazard characteristics. The number of fatalities and the cost of damage are the main proxies for disaster risk, or the dependent variables of the econometric model. Some opt to directly use proxies for the hazards, such as wind-speed, or the magnitude of an earthquake [61,62].

Using earthquake fatalities as the dependent variable, Kahn (2005) aimed to examine the presence and extent of correlation between fatalities, and geography, income, and institutional quality. Anbarci, Escaleras and Register [63] used negative binomial models to examine the influence of inequality on disaster risk, using a political economy model. Kellenberg and Mobarak [64] investigated the correlation of deaths due to floods, earthquakes, landslides, windstorms, and extreme temperature with income level, and demonstrated a non-linear correlation between these measures. In their specifications, risk first increases with income, but beyond a certain income threshold, it starts decreasing.

There is general consensus in these cross-country empirical studies that indeed, a country's level of economic development affects its vulnerability to disasters [58,59,63,65]. However, there is difference in the findings as to the direction of relationship between the level of economic development and disaster (as in Kellenberg and Mobarak [64]), as well as the extent to which the level of development influences vulnerability between developed and developing countries, and/or regions.

Peduzzi et al. [51] use GDP per capita as a proxy for economic development, and find that it is negatively correlated with the fatalities across tropical cyclone, drought, and flood hazards. Likewise, Kahn [65] finds that developed countries have fewer fatalities from earthquakes than those of developing countries. He thus concludes that economic development serves as an "implicit insurance" that cushions the adverse disaster impacts on people. Fewer deaths in developed countries may also be due to a deliberate government policy of placing a higher priority on the protection of lives. This decision to prioritize life may originate from political pressures that apply everywhere, but this can more readily be done with the abundance of resources and technology in these countries.

Of particular interest is the finding that while income is also an important predictor of the number of disaster deaths in both developing and developed countries, the magnitude of its effect in the former group of countries is lower than those in the latter; in developing countries, social conditions matter more than the level of income in reducing the number of deaths, and a more educated citizenry are better able to make informed decisions ensuring their safety.

Kellenberg and Mobarak [64] do not completely refute the findings of a linear disaster-economic development relationship. However, they argue that in the case of developing countries, economic development may actually increase the risk that people face by "changing micro-behavior in such a way so as to increase aggregate exposure to disasters". They also suggest that risk to disasters is also determined by vulnerabilities that are created or enhanced as consequences of development processes. Urbanization, in particular, can have varied effects on risk to disasters. That is, urbanization may reduce or increase vulnerability depending on the context within which it occurs. They find that countries with comparable levels of income, but with different degrees of urbanization can have different risk levels. For competent urban planning, where structures are appropriately designed and where there is adequate capacity to provide economic and social services, urbanization may not necessarily increase the vulnerability to disasters. However, where the capacity of urban areas to deliver key services cannot cope with the rapid influx of population (as is the often the case in developing countries), urbanization may lead to increased exposure and vulnerability to disasters. Employment opportunities in dense urban areas attract low-income families, even if relocation to the urban fringe means increased exposure to disasters. Hence, urbanization in this case increasingly entices people with inherent vulnerability into harm's way (because of relatively fewer resources and weaker capacities to adapt and cope in times of disaster).

The effects of aspects of governance on disaster fatalities and damages have likewise been explored. Kahn (2005) finds that democratic countries experience relatively fewer deaths from disasters than those with other forms of governance. Under a democracy, governments adopt intervening measures to mitigate the adverse consequences of hazards [65]. Raschky [59], as well, finds that a country's institutional framework is a key determinant of vulnerability to disasters. There are fewer fatalities among countries with better institutions because resource allocation is better, and laws and legislations are in place, and they are effectively enforced [59].

Anbarci, Escaleras and Register [63] use inequality, measured in terms of the Gini coefficient, as a proxy for quality of governance and institutions. They argue that a political economy that has low income and high inequality experiences difficulty in generating collective action to provide public goods such as disaster preventive measures. Against this backdrop, these economies suffer more deaths from disasters. In like manner, Kahn [65] finds that, all else being equal, countries with higher inequality suffer more fatalities from earthquakes than countries with lower inequality.

An earlier work by Adger [66] shows similar results. With Vietnam as a case study, which is in transition from a centrally planned economy, he finds that the increasing inequality and the breakdown of collective community action that results from the economic transition have contributed to greater vulnerability. However, he asserts that the resulting institutional change and economic restructuring towards a market system augurs well in terms of reducing vulnerability, as informal coping mechanisms have started to re-emerge.

In a subnational assessment, Yonson, et al. [67] find that in the case of the Philippines provinces, socioeconomic development and good governance are negatively associated with disaster deaths, while unplanned urbanization is positively correlated with mortality. Interestingly, they find that disaster deaths appear to be influenced more by vulnerability and exposure than by the tropical cyclone (hazard) strength.

3.4. Determinants of Economic Resilience

As in the first strand of econometric studies, the second strand likewise finds that countries with higher levels of development are more resilient. Using a panel dataset for 109 countries covering the period 1970–2003, Noy [60] pursued a two-fold inquiry. The first was to quantify the short-run impacts of disasters on the macro-economy, and the second was to examine the determinants of these impacts. This paper finds that disaster damage to capital stock results in reduced short-run macroeconomic growth, and that the value of the damage is reflected in the extent of growth reduction. He further finds that for a disaster of a given magnitude, the corresponding change in output growth (measured

in % of GDP) among small economies and developing countries are greater than those of big economies and developed countries. Interestingly, the direction of change may also vary between these two types of countries. In developing countries, a one standard deviation increase in asset damage results in a 9% reduction in output growth. In the case of developed countries, there is instead a corresponding increase in output growth, albeit minimal. Meanwhile, disasters, alternatively measured in terms of the number of deaths and the affected persons, do not result in statistically observable reductions in output growth.

On Noy's [60] second inquiry, results reveal that countries with a higher income per capita, greater trade openness, and literacy rate, higher levels of public spending, and better institutions, are able to withstand the initial impacts of disasters, and are also able to prevent spillovers. He attributes this to the capacity for resource mobilization to implement the necessary reconstruction. It is worthwhile to note that the above findings already provide preliminary quantitative confirmation that indeed, economic vulnerability and economic resilience are both shaped by the same common economic factors.

Unlike the other econometric studies with a similar research question and methodological approach, Hochrainer [68] establishes a counterfactual to the observed post-disaster GDP. He uses an autoregressive integrated moving average (ARIMA) model to forecast post-disaster GDP level. He then uses the difference between the forecasted and observed GDP level five years after the disaster as the dependent variable in a multivariate regression analysis to determine the influence of explanatory variables on output levels. Like Noy [60], he finds evidence of the negative (but small) consequences of the direct disaster impacts on capital stock to macroeconomic output, though his focus is on the medium-term and in the long-term (five years).

Using this approach, he finds that the inflows of remittances and aid reduce the adverse macroeconomic consequences significantly. In this framework, disasters with damage to capital stock, above a value of 1% of GDP, would overwhelm the internal capacity of the country to self-finance post-disaster reconstruction needs, and hence indicates the importance of aid.

Moreover, that remittances have a significant influence likewise suggests that external sources of finances are also important for individual or household level recovery, perhaps particularly for the affected individuals to go back to productive activities and contribute to output production. Overall, while the direct impacts on capital stock have a strong influence on the follow-on impacts of disasters on output, external funds also have influence on post-disaster dynamics [68].

In a similar attempt to determine welfare changes due to the occurrences of disasters, Mechler [56] measures the corresponding changes in consumption, instead of the usual changes in GDP. In a global sample, Mechler [56] finds that assets losses do not cause significant changes in consumption. However, by narrowing the sample to low-income countries only, he finds that asset losses do adversely alter consumption. In a further inquiry, he finds that inflows of regular and post-disaster aid likewise do not result to significant changes in consumption, except among low-income countries.

Noy and Vu [69] undertook one of the earliest sub-national empirical inquiries on the impact of disasters to output growth, by looking at the experiences of 61 provinces in Vietnam for 1995–2006. They used output level and output growth rate as dependent variables in separate regressions, and the number of deaths to population ratio and value of damaged assets in proportion to GDP as proxies for direct disaster impacts in separate regressions. They found that direct asset damages impacted positively on output growth, with an estimated 0.03% for every percentage point in asset damage as proportional to GDP. In a further inquiry on the heterogeneity of experiences across the eight regions in Vietnam, the results suggested that regions with higher level of development, and that had better access to funds for reconstruction from the central government, experienced this 'creative destruction' dynamics, and a consequent short-run growth spurt in the disaster aftermath. The authors claimed that this provided support for an earlier observation by Cuaresma et al. [70] that areas with high level of development benefit from capital upgrading for assets damaged during a disaster.

The household micro-econometric study of Antilla-Hughes and Hsiang [71] examines tropical cyclones and study the Philippines by constructing a panel data from various nationwide household

surveys and other datasets. The authors find that consequent to the sharp drop in household income due to disasters, are alterations in investment, expenditure, and consumption patterns of the households surveyed. There is an evident reduction in investments in human capital, resulting in children dropping out from school, and a reduction in household expenditures on medicine and nutritious foods. Several other papers report similar findings for other case studies (surveyed in Karim and Noy, [72]); but neither of these examines whether these short-term patterns of impact on investments in health and education have any long-term impacts. An exception is Caruso and Miller [73], who find that these impacts on education persist even in the second generation after a catastrophic event (in their case, an earthquake in Peru in 1970).

Arouri, et al. [74] undertook a household-level study in Vietnam to determine the effects of floods, storms, and droughts on household welfare, and determined the characteristics of households and communities that made them resilient to the adverse disaster impacts. In their model, using commune-level fixed-effects, they ran separate regressions for each of four dependent variables: income per capita, per capita consumption expenditure, poverty status of households, and the share of income of alternative sources of income. The authors posited that resilient households experience relatively less adverse disaster impacts on their welfare, as proxied by these indicators [74].

For storm-related disasters, their results revealed that those households with fewer members of working age, those with more household members, and those belonging to the ethnic minority groups are all less resilient. The authors' interpretation is that households with fewer members of working age cannot increase labor supplies to generate income to cover the losses in income and consumption. Meanwhile, large households have lower per capita income, and minority groups have lower access to services that will help in smoothing their consumption. Internal remittances are found to be important contributors of resilience to all three hazards. Likewise, access to finance—such as microfinancing, international remittances and social allowances—is found as a significant contributor to resilience. Yet, in communes with either more equal distribution of expenditure (as measured by a commune's Gini coefficient of expenditures) or higher level of average per capita expenditure, households are found to be more resilient. Furthermore, households with a high level of education are also more resilient to the adverse effects of floods and droughts.

The vast majority of the above econometric studies in either research strand focuses on the macroeconomic and national-level assessments. The results of global and country-level studies provide general indications on what broadly determines vulnerability and resilience across countries, and how each country fares against others. However, sub-national-level assessments are better able to capture context-specific concerns; hence, their findings have greater practical usefulness to any country.

Moreover, at the time of writing, we find no micro-econometric analysis along the first strand of inquiry on the determinants of deaths, injuries, diseases, or property damage at the household or firm levels. The works of Antilla-Hughes and Hsiang [71], and Arouri, Nguyen and Youssef [74] are two of a few studies along the second strand of inquiry. Results from micro-level analysis would provide insights on other factors that likewise have important influences on economic vulnerability and resilience, and would allow for comparison of the relative importance of these factors at the micro and macro levels.

The focus of econometric studies on the macro level of inquiry is likely due to the complexity of using a single econometric model to capture both levels, and, perhaps, to the difficulty of accessing or building a useful micro-level dataset. Other useful frameworks for a macro–micro analysis include computable general equilibrium methods (as in Rose [43]), partial equilibrium analysis (such as Hallegatte, et al. [75]), and other mathematical algorithms.

Vulnerability and resilience have typically been studied separately, even within disciplines. However, studying them simultaneously will assist in painting a more comprehensive picture of total disaster impacts. It may also subsequently aid in the identification of a comprehensive package of interventions that addresses the various channels through which vulnerabilities are reduced and resilience enhanced. A deeper appreciation of the channels of causality involved allows for better

informed pre- and post-disaster policies. Thus, it is important for vulnerability and resilience to be studied simultaneously, yet measured separately, as one cannot fully address one without addressing the other.

4. Synthesis and Implications for Policy

Some broad agreements have been reached towards achieving greater precision in the conceptualization of both vulnerability and resilience. In the context of natural hazards and disasters, vulnerability and resilience are interrelated. Yet, despite having similar underlying factors, they refer to different things. Vulnerability is mainly considered as a pre-disaster concern that refers to the conditions that make the confluence of a hazard, and a system's exposure to it, result in a disaster. Resilience is largely, but not entirely, a post-disaster concern; it refers to the conditions that makes the affected systems withstand and bounce back from the disaster experienced. It is also a pre-disaster concern in as much as a system's ability to withstand adverse disaster impacts is largely influenced by pre-disaster conditions.

Likewise, several broad conclusions and useful insights for DRR policy decisions can be generated from the empirical findings described here. It is worthwhile to note that 10 of the 17 SDGs have specific targets that are related to DRR [76]. The 10 SDGs with DRR-related targets are: Goal 1—No poverty, Goal 2—Zero hunger, Goal 3—Good health and well-being, Goal 4—Quality education, Goal 6—Clean water and sanitation, Goal 9—Industry, innovation and infrastructure, Goal 11—Sustainable cities and communities, Goal 13—Climate action, Goal 14—Life below water, and Goal 15—Life on land. Thus, building disaster resilience and reducing risk are considered core strategies that will contribute to attaining the SDG.

The empirical findings provide systematic support for the hypothesis that apart from the characteristics of the hazards, the potential for people and systems to avoid adverse impacts, and their capacity to withstand and rebound from a disaster are influenced by a confluence of socio-economic factors. Hence, DRR measures must include an appropriate mix of structural and non-structural measures that aim to affect these factors. The conceptual and empirical findings imply that in the terms of DRR priorities, vulnerability is typically linked to prevention, preparedness, and mitigation, while resilience is linked to response, rehabilitation, reconstruction, and recovery, as well as mitigation to address future risks.

There is a general consensus in the cross-country studies that low-income countries are more vulnerable and less resilient than countries with higher levels of development. What this means in policy terms is that assistance and investments in development yield the greatest benefits in terms of lives spared and assets protected from disasters if low income countries, particularly those with high exposure, are favored. This is consistent with the SDG 1 target of building the "resilience of the poor and those in vulnerable situations and reduce their exposure" to disasters and other shocks [76]. Moreover, the findings that social conditions may matter more than the level of income in reducing the number of deaths, likewise indicates the nature of intervention that is needed to significantly address vulnerability among these countries. SDG 11 calls for the provision of basic services for all, and the protection of vulnerable groups.

Moreover, findings consistently suggest that policies that are most effective in minimizing impacts on economic flows and other spillover effects at the macroeconomic level mostly deal with the provision of adequate access to funds, including aid, to speed up the reconstruction, rehabilitation, and subsequent economic recovery. This is consistent with another SDG 11 target of providing financial support to contribute towards achieving the goal of making sustainable communities and cities. External sources of funds, such as aid and remittances, are likewise critical for household-level recovery, particularly among the financially constrained; though internal sources, including saving, are also important. With the apparent critical role of credit and access to funding, more research on financial risk-transfer tools, such as insurance, as a tool for building resilience is still required.

To date, the intensified application of economic theory has resulted in important advances in concretizing the concepts of economic vulnerability and resilience, as well as in measuring them. Nonetheless, alongside these advances, one can identify some much-needed refinements, including: adoption of an integrated approach for the study of both economic vulnerability and economic resilience, covering both macro and micro levels, as well as from the short-run to the long-run, application of a systematic method in identifying a plausible set of indicators to capture and measure the distinct economic vulnerability and resilience of each element in different contexts and circumstances, determining the relative importance of common underlying factors in influencing economic vulnerability and economic resilience at the macro and micro levels, and translation of the measures and findings into tools for systematic identification and prioritization of a set of policies and actions to reduce vulnerability and to strengthen resilience.

We note some caveats to our approach and findings. We covered only quantitative studies, and the synthesis focused on the findings of studies using econometric methods. We acknowledge that there is a need to apply a careful and comparative examination of results for both qualitative and quantitative studies, so that one can successfully and reliably identify a plausible set of indicators that measure and may even determine a robust menu of policy options to reduce economic vulnerability and increase resilience. While we are unable to do this synthesis of quantitative and qualitative analysis within this paper, we consider this as a worthwhile research agenda that can be pursued in collaborative interdisciplinary work.

Overall, the ultimate aim is for a sound and widely-accepted set of tools for systematically identifying and prioritizing a set of policies and actions to reduce vulnerability, and to strengthen resilience in different contexts (e.g., developed and developing countries), timeframes (e.g., long-, medium-, and short-run), levels of assessment and governance (e.g., macro and micro; household community, city, province, country), hazard types (e.g., meteorological and geologic), and elements at risk.

References

1. Blaikie, P.; Cannon, T.; Davis, I.; Wisner, B. *At Risk: Natural Hazards, People's Vulnerability, and Disasters*; Routledge: London, UK, 1994.
2. Westen, C.; Kingma, N. Vulnerability Asessment. In *Vulnerability Assessment: Disastance Education Course Guidebook*; United Nations University—ITC School of Disaster Geoinformation Management: Tokyo, Japan, 2009.
3. Wisner, B.; Blaikie, P.; Cannon, T.; Davis, I. *At Risk: Natural Hazards, People's Vulnerability, and Disasters*, 2nd ed.; Routledge: London, UK, 2004.
4. Kates, R.W. Natural Hazard in Human Ecologica Perspective: Hypothesis and Models. *Econ. Geogr.* **1971**, *47*, 438–451. [CrossRef]
5. O'Keefe, P.; Westgate, K.; Wisner, B. Taking the naturalness out of natural disasters. *Nature* **1976**, *260*, 566–567. [CrossRef]
6. Dacy, D.C.; Kunreuther, H.K. *The Economics of Natural Disasters*; Free Press: New York, NY, USA, 1969.
7. Albala-Bertrand, J.M. *Political Economy of Large Disasters*; Clarendon Press: Oxford, UK, 1993.
8. Cavallo, E.; Noy, I. Natural Disasters and the Economy—A Survey. *Int. Rev. Environ. Resour. Econ.* **2011**, *5*, 63–102. [CrossRef]
9. Holland, J.H. Studying Complex Adaptive Systems. *J. Syst. Sci. Complex.* **2006**, *19*, 1–8. [CrossRef]
10. United Nations (UN). *Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction*; United Nations: Geneva, Switzerland, 2016; p. 41.

11. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Impacts, Adaptaion, and Vulnerability*; World Meteorological Organization: Geneva, Switzerland, 2014.

12. United Nations International Strategy for Disater Reduction (UNISDR). *UNISDR Terminology on Disaster Risk Reduction*; United Nations International Strategy for Disater Reduction: Geneva, Switzerland, 2009.

13. Birkmann, J. (Ed.) Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definitions. In *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*; United Nations University: New York, NY, USA, 2006.

14. Gaillard, J. Vulnerability, capacity and resilience: Perspectives for climate and development policy. *J. Int. Dev.* **2010**, *22*, 218–232. [CrossRef]

15. Thywissen, K. Core terminology of disaster reduction. In *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*; Birkmann, J., Ed.; United Nations University: New York, NY, USA, 2006.

16. Villagran de Leon, J.C. *Vulnerability: A Conceptual and Methodological Review*; UNU Institute for Environment and Human Society (UNU-EHS): Bonn, Germany, 2006.

17. Miller, F.; Osbahr, H.; Boyd, E.; Thomalla, F.; Bharwani, S.; Ziervogel, G.; Walker, B.; Birkmann, J.; van der Leeuw, S.; Rockström, J.; et al. Resilience and vulnerability: Complementary or conflicting concepts? *Ecol. Soc.* **2010**, *15*, 11. [CrossRef]

18. UNDRO. Natural Disasters and Vulnerbality Analysis. In *Rerport of Expert Group Meeting*; United Nations Disaster Relief: Geneva, Switzerland, 1979.

19. Wisner, B.; Gaillard, J.; Kelman, I. *The Routledge Handbook of Hazards and Disaster Risk Reduction*; Routledge: London, UK, 2012.

20. Pelling, M. *The Vulnerability of Cities: Natural Disasters and Social Resilience*; Earthscan Publications Ltd.: London, UK, 2003.

21. IPCC. *Climate Change 1995*; Intergovernmental Panel on Climate Change: Cambridge, UK, 1996.

22. IPCC. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*; Intergovernmental Panel on Climate Change: Cambridge, UK, 2001.

23. Alexander, D.E. Resilience and disaster risk reduction: An etymological journey. *Nat. Hazards Earth Syst. Sci.* **2013**, *13*, 2707–2716. [CrossRef]

24. Holling, C. Resilience and Stability of Ecological Systems. *Annu. Rev. Ecol. Syst.* **1973**. [CrossRef]

25. Mileti, D.S. *Disasters by Design a Reassessment of Natural Hazards in the United States*; Joseph Henry Press: Washington, DC, USA, 1999; p. 371.

26. Correia, F.N.; Santos, M.A.; Rodrigues, R.R. Engineering Risk in Regional Drought Studies. In *Engineering Reliability and Risk in Water Resources*; Duckstein, L., Plate, E., Eds.; Springer: Dordrecht, The Netherlands, 1987; Volume 124, pp. 61–86.

27. Pimm, S.L. The complexity and stability of ecosystems. *Nature* **1984**, *307*, 321–326. [CrossRef]

28. Bruneau, M.; Chang, S.E.; Eguchi, R.T.; Lee, G.C.; O'Rourke, T.D.; Reinhorn, A.M.; Shinozuka, M.; Tierney, K.; Wallace, W.A.; Winterfeldt, D.V. A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthq. Spec.* **2003**, *19*, 733–752. [CrossRef]

29. Hallegatte, S. Economic Resilience: Definition and Measurement. In *Policy Research Working Paper*; World Bank Group: Washington, DC, USA, 2014; Volume WPS6852.

30. Rose, A. *Economic Resilience to Disasters*; CREATE Research Archive: Sacramento, CA, USA, 2009.

31. Alwang, J.; Siegel, P.; Jorgensen, S. *Vulnerablity: A View from Different Disciplines*; The World Bank: Washington, DC, USA, 2001.

32. Moret, W. *Vulnerability Assessment Methodologies: A Review of Literature*; United States Agency for International Development: Washington, DC, USA, 2014.

33. Briguglio, L. Economic vulnerability and resilience: Concepts and measurements. In *Economic Vulnerability and Resilience of Small States*; Briguglio, L., Kisanga, E.J., Eds.; Islands and Small States Institute of the University of Malta: Msida, Malta, 2004.

34. Briguglio, L.; Cordina, G.; Farrugia, N.; Vella, S. Economic Vulnerability and Resilience: Concepts and Measurements. *Oxf. Dev. Stud.* **2009**, *37*, 229–247. [CrossRef]

35. Briguglio, L.; Galea, W. Updating the Economic Vulnerability Index. In *Occasional Chapters on Islands and Small States*; Islands and Small States Institute of the University of Malta: Msida, Malta, 2003.

36. GFDRR. *Damage, Loss and Need Assessment—Tools and Methodology*; GFDRR: Washington, DC, USA, 2014.

37. Economic Commission for Latin America and the Caribbean (ECLAC); The World Bank (WB). *Handbook for Estimating the Socio-Economic and Environmental Effects of Disaster (ECLAC Handbook)*; United Nations-Economic Commission for Latin America and the Caribbean (UN-ECLAC): Santiago, Chile; International Bank for Reconstruction and Development (The World Bank): Santiago, Chile, 2003.

38. Rose, A. Economic Principles, Issues, and Research Priorities in Hazard Loss Estimation. In *Modeling Spatial and Economic Impacts of Disasters*; Okuyama, Y., Chang, S., Eds.; Springer: Heidelberg, Germany, 2004.

39. National Research Council (NRC). *Improved Seismic Monitoring–Improved Decision-Making: Assessing the Value of Reduced Uncertainty*; National Research Council: Washington, DC, USA, 2005.

40. National Research Council (NRC). *National Earthquake Resilience: Research, Implementation and Outreach*; NRC: Washington, DC, USA, 2011.

41. National Research Council (NRC). *Disaster Resilience: A National Imperative*; NRC: Washington, DC, USA, 2012.

42. Natural Hazard Mitigation (NMC). Saves: An Independent Study to Assess the Future Savings from Mitigation Activities. In *Report to U.S. Congress on Behalf of the National Institute of Building Sciences*; Multihazard Mitigation Council: Washington, DC, USA, 2005; Volume 2.

43. Rose, A. Defining and measuring economic resilience to disasters. *Disaster Prev. Manag.* **2004**, *13*, 307–314. [CrossRef]

44. Hallegatte, S.; Przyluski, V. The Economics of Natural Disasters: Concepts and Methods. In *Policy Research Working Paper*; World Bank Group: Washington, DC, USA, 2010.

45. Rose, A.; Krausmann, E. An economic framework for the development of a resilience index for business recovery. *Int. J. Disaster Risk Reduct.* **2013**, *5*, 73–83. [CrossRef]

46. Angeon, V.; Bates, S. Reviewing Composite Vulnerability and Resilience Indexes: A Sustainable Approach and Application. *World Dev.* **2015**, *72*, 140–162. [CrossRef]

47. Cutter, S.L.; Barnes, L.; Berry, M.; Burton, C.; Evans, E.; Tate, E.; Webb, J. A place-based model for understanding community resilience to natural disasters. *Glob. Environ. Chang.* **2008**, *18*, 598–606. [CrossRef]

48. Cutter, S.L.; Boruff, B.J.; Shirley, W. Social Vulnerability to Environmental Hazards. *Soc. Sci.* **2003**, *84*, 242–261. [CrossRef]

49. Pelling, M. Review of global risk index projects: Conclusions for sub-national and local approaches. In *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*; Birkmann, J., Ed.; United Nations University: New York, NY, USA, 2006; pp. 151–170.

50. Peduzzi, P. The Disaster Risk Index: Overview of a quantitative approach. In *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*; Birkmann, J., Ed.; United Nations University: New York, NY, USA, 2006; pp. 171–181.

51. Peduzzi, P.; Dao, H.; Herold, C.; Mouton, F. Assessing global exposure and vulnerability towards natural hazards: The Disaster Risk Index. *Nat. Hazards Earth Syst. Sci.* **2009**, *9*, 1149–1159. [CrossRef]

52. United Nations Development Programme-Bureau of Crisis Prevention and Recovery (UNDP-BCPR). *A Global Report: Reducing Disaster Risk, a Challenge for Development*; United Nations Development Programme-Bureau of Crisis Prevention and Recovery: New York, NY, USA, 2004.

53. De Groeve, T.; Poljansek, K.; Vernaccini, L. Index for Risk Management—INFORM. In *Concepts and Methodology (Version 2015)*; Joint Research Center of the European Commission: Luxemberg, 2015.

54. Joint Research Center of the European Commission (JRC-EC). *INFORM Results and User Guide (2014 Beta Version)*; Joint Research Center of the European Commission: Brussels, Belgium, 2014.

55. Birkmann, J. Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. *Environ. Hazards* **2007**, *7*, 20–31. [CrossRef]

56. Mechler, R. Disaster and Economic Welfare: Can National Savings Help Explain Post-disaster Changes in Consumption. In *Policy Research Working Paper*; The World Bank: Washington, DC, USA, 2009; Volume WPS4988. [CrossRef]

57. Nordhaus, W.D.; Tobin, J. Is Growth Obsolete. In *Economic Research: Retrospect and Prospect*; NBER: Berlin, Germany, 1972; Volume 5.

58. Toya, H.; Skidmore, M. Economic development and the impacts of natural disasters. *Econ. Lett.* **2007**, *94*, 20–25. [CrossRef]

59. Raschky, P.A. Institutions and the losses from natural hazards. *Nat. Hazards Earth Syst. Sci.* **2008**, *8*, 627–634. [CrossRef]

60. Noy, I. The macroeconomic consequences of disasters. *J. Dev. Econ.* **2009**, *88*, 221–231. [CrossRef]

61. Felbermayr, G.; Gröschl, J. Naturally negative: The growth effects of natural disasters. *J. Dev. Econ.* **2014**, *111*, 92–106. [CrossRef]

62. Strobl, E. The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions. *J. Dev. Econ.* **2012**, *97*, 130–141. [CrossRef]

63. Anbarci, N.; Escaleras, M.; Register, C.A. Earthquake fatalities: The interaction of nature and political economy. *J. Public Econ.* **2005**, *89*, 1907–1933. [CrossRef]

64. Kellenberg, D.K.; Mobarak, A.M. Does rising income increase or decrease damage risk from natural disasters? *J. Urban Econ.* **2008**, *63*, 788–802. [CrossRef]

65. Kahn, M.E. The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions. *Rev. Econ. Stat.* **2005**, *87*, 271–284. [CrossRef]

66. Adger, W.N. Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Dev.* **1999**, *27*, 249–269. [CrossRef]

67. Yonson, R.; Noy, I.; Gaillard, J.C. The measurement of disaster risk: An example from tropical cyclones in the Philippines. *Rev. Dev. Econ.* **2018**, *22*, 736–765. [CrossRef]

68. Hochrainer, S. *Assessing the Macroeconomic Impacts of Natural Disasters: Are There Any?* The World Bank: Washington, DC, USA, 2009. [CrossRef]

69. Noy, I.; Vu, T. The Economics of Disasters in a Developing Country: The Case of Vietnam. *J. Asian Econ.* **2010**, *21*, 345–354. [CrossRef]

70. Cuaresma, J.C.; Hlouskova, J.; Obersteiner, M. Natural disasters as creative destruction? Evidence from developing countries. *Econ. Inquiry* **2008**, *46*, 214–226. [CrossRef]

71. Antilla-Hughes, J.K.; Hsiang, S.M. *Destruction, Disinvestment, and Death: Economic and Human Losses Following Environmental Disaster*; National Bureau of Economic Research (NBER): Boston, MA, USA, 2013.

72. Karim, A.; Noy, I. Poverty, inequality and natural disasters—A survey. In *SEF Working Paper*; Victoria University of Wellington: Wellington, New Zealand, 2013.

73. Caruso, G.; Miller, S. Long run effects and intergenerational transmission of natural disasters: A case study on the 1970 Ancash Earthquake. *J. Dev. Econ.* **2015**, *117*, 134–150. [CrossRef]

74. Arouri, M.; Nguyen, C.; Youssef, A.B. Natural Disasters, Household Welfare, and Resilience: Evidence from Rural Vietnam. *World Dev.* **2015**, *70*, 59–77. [CrossRef]

75. Hallegatte, S.; Bangalore, M.; Vogt-Schilb, A. *Socioeconomic Resilience: Multi-Hazard Estimates in 117 Countries*; World Bank Group: Washington, DC, USA, 2016.

76. UNISDR. *Disaster Risk Reduction and Resilience in the 2030 Agenda for Sustainable Development*; UN Office for Disaster Risk Reduction: Geneva, Switzerland, 2015.