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Natural disasters, the economy and population vulnerability as a vicious cycle with exogenous hazards

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ABSTRACT

One way to understand the growing impact of disasters is as the output of a positive feedback, or reinforcing, loop. This paper hypothesizes that population vulnerability of a country transforms exogenous hazards to disaster impact for that country, which negatively impacts its economy as measured by per capita income and its growth. This impact in turn increases the vulnerability of the country's population thus creating a reinforcing loop. Therefore, like the output of any positive feedback loop, disaster impact would grow exponentially. Having analysed data over 50 years (1963–2012) and 179 countries, we find the results to be consistent with this conceptual model. We also find that disaster impact worldwide has indeed grown exponentially over this period even after normalizing for the growing global population and global income. These findings indicate the existence of a feedback loop that requires strategic rethinking about disaster management and development jointly to break this vicious cycle.

1. Introduction

The increasing number and impact of natural disasters over time has led many to posit *vicious cycles* comprising disaster impact and any subset of deforestation, poverty, urbanisation, vulnerability and other factors (cf. Manuel-Navarrete et al., 2007; McEntire, 2001; Barrett and Carter, 2000; Vatsa, 2004). So far, however, little empirical evidence has been provided to support the existence of these vicious cycles. This paper seeks to provide some initial evidence.

One way to model a simple vicious cycle is as a positive feedback loop (cf. Sudling, 2013), i.e., a reinforcing loop, as in control theory. We conceptualize such a loop with disaster impact as the output and natural hazards as the exogenous input. We posit that population vulnerability is positively linked to disaster impact, disaster impact negatively impacts the economy of a country as measured by per capita income and its growth, and these in turn affect the vulnerability of the country's population. As with any positive feedback loop, we expect the output, in this case the disaster impact, to grow exponentially over time.

By analysing country-level disaster, economic and hazard data for five decades (1963–2012), we find our threefold results to be consistent with this conceptual model: *First*, the population's vulnerability transforming a given hazard (an earthquake) is positively linked to disaster impact for the country (Peduzzi et al., 2012). *Second*, disaster impact is negatively linked to a country's economy as reflected by its national income and its growth, which in turn are negatively linked to the vulnerability of its population (child mortality under age five and incidence of tuberculosis), thus creating reinforcing feedback. *Third*, time-series analysis shows exponentially increasing impact when impact is measured by the total number of people affected every year or property damage worldwide, even when we normalize the impact by population or income respectively. The results therefore provide initial evidence for a positive feedback loop at work. The implication is that we need to develop a strategic view of humanitarian operations encompassing both humanitarian relief and development to interrupt this vicious cycle of disasters.

This paper contributes to the humanitarian operations literature in at least two ways: (1) Analysis of country-level data in this paper sets the stage for a grounded "systems view" to "replace well-intended intuition" (Starr and Van Wassenhove, 2014). This work provides the empirical basis for building *system dynamics* (SD) and other simulation-based models to look for longer-term solutions for intervention than those in place currently. It also provides a starting point for additionally incorporating hazards like climate change and its varied impact on different countries. (2) By building

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on the disaster-and-development literature, this work provides a foundation for building theory for strategic humanitarian operations allowing us "to harmonize short-term humanitarian and long-term development efforts in the same region" (Kovács and Spens, 2011). The analysis complements the 'micro' context of specific cases and situations in the humanitarian literature (cf. Tomasini and Van Wassenhove, 2009; Pedraza Martinez et al., 2011) with a 'macro' context at the country level across the globe. The paper and the feedback loop allow for links to be made with the development literature (cf. Shepherd et al., 2013; Fothergill and Peek, 2004; Bankoff et al., 2004; Pelling, 2003; Blakie et al., 1994).

The managerial significance of this work is that governments, international bodies like the World Bank and the International Federation of the Red Cross and Red Crescent Societies (IFRC) as well as regional NGOs can use SD models based on this paper to allocate resources more cost-effectively across response, reconstruction, preparedness and prevention than is currently being done.[1] Humanitarian organizations can use this work to seek support to "develop more sustainable solutions from social, ecological, and economical perspectives" (Kovács and Spens, 2011) *beyond* response and preparedness. The existence of such feedback loops requires rethinking disaster management and development jointly as ways to interrupt feedback, whether by way of prevention, mitigation, development or reconstruction (Rodes et al., 2008; LOG, 2014). Both development efforts and humanitarian operations can align themselves around the same specific vulnerability metrics (Birkmann, 2006; Cutter and Finch, 2008), an example being *child mortality under age five* (UNICEF, 2000) as a *lagging* indicator for development and as a *leading* indicator for disaster impact.

The rest of the paper is organized as follows: §2 provides the theoretical background on positive (i.e., reinforcing) feedback loops as well as existing research to support the relations within a reinforcing feedback loop structure. §3 presents the chosen measures, data sources and methods, and §4 provides the results. Finally, §5 discusses the implications and limitations of this work as well as opportunities for further research.

2. Theory

The literature (cf. Manuel-Navarrete et al., 2007; McEntire, 2001; Barrett and Carter, 2000; Vatsa, 2004) generally suggests *natural disasters* and *poverty* to be intimately linked via vicious cycles. Other concepts entailed in posited vicious cycles include deforestation, poverty, urbanisation, vulnerability and other factors. However, there is dearth of empirical evidence in support of these vicious cycles.

Swedish economist Gunnar Myrdal furthered the development and use of *circular and cumulative causation* (CCC) with core variables and with multiple links to propose multiple causes in socio-economic settings. For instance, he studied Asian underdevelopment using CCC (cf. O'Hara, 2008). However, the large number of concepts used in any such model and bidirectional links between them make it difficult to test these models.

To provide empirical evidence for a posited 'vicious cycle', we consider the *positive feedback loop* from control theory as used for instance in engineering, particularly in electronics. The forward part of this loop comprises an input that is transformed into an output. The feedback is the output, transformed by another function B, going back with the input − if it adds to the input, we get unlimited amplification over time, leading to ever-increasing output and we call this a *positive* feedback loop. In such a loop, the transformation function is itself transformed by the output. (If the feedback subtracts from the input, the output reduces over time and we call this a *negative* feedback loop.)

In particular, we are interested in *vulnerability* as the transformation function that converts hazards into disasters: a country with higher vulnerability would have a bigger disaster with more people affected than a country with lower vulnerability, all else being equal including the physical intensity of the hazard. Vulnerability is thus the propensity across different population segments to be affected by natural hazards and other shocks (LOG, 2014; Blakie et al., 1994; Cannon, 1994; Anderson, 1995). Vulnerability studies were instrumental in the 1990s in changing the thinking that the impact of 'natural disasters' was manmade. The literature linking disasters and vulnerability is largely conceptual (cf. Cannon, 1994) and with divergent understanding of vulnerability, which is sometimes conflated with *poverty* (cf. Rodriguez-Oreggia et al., 2013). In this paper we view poverty separately as an attribute of a country or region.

Consider a country facing a constant hazard rate H as the exogenous input. The transformation function is the vulnerability $V(t)$, which converts the input into disaster impact $D(t)$ as output. This output also worsens the state of the economy $E(t)$, which in turn increases the vulnerability $V(t)$. With such an arrangement, the disaster impact would keep growing as feedback would keep increasing the amplifying effect of the transformation even with the hazard rate remaining constant (Fig. 1).

For some constants k_1, k_2, and k_3, we *propose* that vulnerability transforms hazards into disaster impact so that

$$D(t) = k_1 H V(t) \tag{1}$$

Consequently, $D'(t) = k_1 H V'(t)$, the prime symbol reflecting the first derivative with respect to time. The feedback function reflecting the economy $E(t)$ is such that the rate of change in the economy $E'(t)$ is proportional to the disaster impact at time t

$$E'(t) = k_2 D(t) \tag{2}$$

Moreover, vulnerability depends on the economy so that

$$V(t) = k_3 E(t) \tag{3}$$

so that $V'(t) = k_3 E'(t)$.

From (1) and (3), $D'(t) = k_1 H V'(t) = k_1 k_3 H E'(t)$. Substituting (2), we have

$$D'(t) = k_1 k_2 k_3 H D(t)$$

Solving this differential equation, we obtain

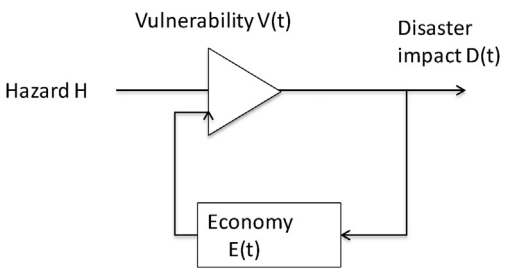

Fig. 1. Conceptualisation of disasters as a positive feedback loop at the country level entailing the economy with population vulnerability transforming exogenous hazards to disasters.

[1] The World Bank (2013) provides similar advice using a risk management perspective.

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