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Buttressing Supply Chains against Floods in Asia for Humanitarian Relief and Economic Recovery

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Abstract: Floods are the most frequent category of disasters worldwide. Among all geographical regions, Asia has suffered the most. While there are several ongoing humanitarian efforts and initiatives, we believe there is a new opportunity to coordinate "last mile" humanitarian efforts in the event of a flood using micro-retailers. Because micro-retailers are the 'last mile' nodes in traditional retail supply chains in many Asian countries, we propose the use of social enterprise to buttress these supply chains for distribution of essential goods by coordinating with micro-retailers before and after floods. We also present a stylized model to quantify the benefits of doing so.

Keywords: supply chain design; floods; natural disasters; humanitarian relief; social enterprise; buttressed supply chains; disaster relief

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1. Introduction

For the decade ending in 2010, floods accounted for nearly half of all natural disasters. Floods affected a large number of people especially in Asia: eight out of the ten deadliest floods worldwide from 2001-2010 occurred in Pakistan, India, and Bangladesh. Despite the fact that the number of floods per year has been increasing exponentially since 1900, there is very little in the operations literature on humanitarian supply chains that deals with floods. Unlike earthquakes, floods are more predictable in terms of timing and location. Therefore, there is an opportunity to involve "local entities" for better preparedness and mitigation. Thus, we seek to answer the question: what type of supply chain can facilitate humanitarian relief and hasten economic recovery in case of floods, especially in the Asian context?

Our proposed answer lies in "buttressing" traditional supply chains of essential goods to improve humanitarian relief and to aid economic recovery for all involved parties after the flood.[1] Because micro-retailers are essentially the 'last-mile' nodes in retail supply chains in Asia,[2] such buttressing would have to involve micro-retailers. Our idea involves a (for-profit or not-for-profit) social enterprise that would coordinate preparation for and response to a flood. Specifically, the social enterprise would buy essential consumer goods from the upstream supply chain nodes (manufacturers/distributors) and pre-position inventory in temporarily leased earmarked spaces before an anticipated flood. It would replenish pre-registered micro-retailers during the flood and during the recovery period. Thus, the micro-retailers would be able to continue selling to their local customers, now 'beneficiaries' (i.e., flood affected individuals), who would pay for essential goods by using cash or certain vouchers provided by the government or international NGOs. When humanitarian aid stops, the traditional supply chain operations would be restored, and erstwhile beneficiaries can continue buying from the micro-retailers who would replenish their stock from wholesalers as they did before the flood.

We provide an 'engineering' solution that calls for the use of various "existing elements" of humanitarian efforts to develop local solutions for floods in Asia. Although our proposed solution is not fundamentally novel in itself, it does contribute to the

operations literature that has not delved much into the specifics of flood relief so far. We also contribute to the supply-chain literature via our notion of buttressed supply chains that use a "temporary" channel when the regular supply chain is disrupted. Additionally, we present a simple model to quantify the benefits of our proposed solution.

2. The 'Problem' of Floods in Asia

In 2000, a billion people were living in areas vulnerable to a 100-year flood and it is expected to double by 2050 (UNU 2004).[3] In Asia, the number of floods has been growing exponentially over 1910-2010 (Figure 1), impacting many people over the past century (Figure 2). Currently, there is a general belief that climate change will lead to more large-scale floods (e.g., the floods in North Korea (2012) and Thailand (2011)).

Insert Figure 1 somewhere here

Insert Figure 2 somewhere here

Asia has been affected by more flood-related disasters than any other continent in the world, accounting for 228,000 deaths and 93% of all floods-related deaths in the world over the decade 1987-1997 (UNU 2004). This percentage rises to 99% if we consider the past 110 years (Table 1). Also, flood risks remain high in the same regions of Asia (Bangladesh, India, and Pakistan) as of 2011 (Figure 3).

	Incidence	Impact		
	Total # of events	*Total killed*	*Total affected*	*Estimated Damage*
Africa	22%	0%	2%	1%
Americas	23%	0%	2%	16%
Asia	**37%**	**99%**	**96%**	**61%**
Europe	15%	0%	0%	19%
Oceania	2%	0%	0%	3%
Total %	100%	100%	100%	100%
TOTAL	2,084	4.4 million	2.3 billion	US$ 344.5 billion

Table 1: Incidence of general floods, not including flash floods or unspecified floods, and their impact in different continents over 1900-2012 (Source: EM-DAT: The OFDA/CRED International Disaster Database).

Insert Figure 3 somewhere here

As floods have essentially become an annual occurrence, the number of people affected each year is quite stable in large and populated countries like India and Indonesia (Figure 4) across the three decades from 1980-2010.

Insert Figure 4 somewhere here

Despite these statistics, a disproportionate amount of the operations (OR/ OM) literature on humanitarian supply chains has focused on earthquakes and international humanitarian efforts, which require solutions that originate outside the affected region. In contrast to earthquakes and droughts, local solutions can be developed for mitigation and preparedness for general floods (not including 'flash' floods). There are other pertinent differences too that imply that the humanitarian relief efforts for floods need to be planned differently from those directed towards earthquakes or droughts – see Table 2.

	Earthquakes	General floods	Droughts
Onset time	Very fast	Medium	Very slow
Origin of solutions	Primarily external to the affected region	Primarily local to the region except for rare floods where external solutions are needed	Primarily external to the affected region
Arrival time predictability and prediction lead time	Highly unpredictable in time as well as in location.	Timing during the year is predictable and even intensity can be predicted with a few days of lead time using satellite imagery; locations can be identified as being more flood-prone than others using historical data	Prediction over long time, however, those affected have no means to act
Location of disaster	Although some sites are more vulnerable than others, earthquake epicenter location can vary over a large area even if the earthquake entails the same tectonic plates	In low lying areas along the river. Although, rivers used to change direction with floods, most rivers now have set boundaries owing to urbanization.	Same areas year-after-year – drought may go on for many years.
People	Generally stay where they are	May need to be moved to non-flooded areas	Area too widespread for people to move; national boundaries get in the way
Items needed	Blankets and clothing, besides foods and water (could be in cold weather)	Instant food and drinking water primarily; water-borne diseases are a major threat.	Food and water.
Transportation relief efforts	Road, helicopter	Road, boat, helicopter with 'last mile' efforts on foot, rubber boat, and even ox-carts.	Internationally led traditional supply chains – air and road.
Demographics of those affected	Could affect anyone, depending on location and type of housing.	Primarily the 'poor' as it is generally the poorest who have to live in flood-prone areas in any city.	The 'poor'.

Table 2: Some differences between earthquakes, general floods and droughts pertinent to humanitarian operations

Economic recovery after a disaster remains a thorny problem. A full year after the 2010 floods in Pakistan, over 1.6 million flood-affected individuals remained homeless despite the efforts of many humanitarian organizations. UN Food and Agricultural Organization (FAO) warned that many displaced people in Pakistan would require help till 2013 with economic recovery a "distant dream" (UN 2011).

3. Existing Solutions

Humanitarian relief operations often entail the involvement of the International Federation of Red Cross and Red Crescent Societies (IFRC) along with their national societies, Oxfam and World Food Program (WFP) to carry out massive logistical efforts to help victims affected by any type of disaster including "massive" floods. We now examine these efforts from two perspectives: as supply chain flows and as disaster relief efforts, with an eventual aim to identify gaps in the existing solutions for flood relief.

3.1 Supply Chain Flows for Flood Relief

Because supply chain operations canonically comprise material flows, information flows and cash flows, we can examine existing humanitarian relief operations as follows:

a) Material flows: NGOs are working with logistics providers for humanitarian relief. For example, WFP's logistics operations in China, Myanmar, India, and Philippines are now supported by Logistics Emergency Teams (LETs) established by TNT, UPS, and Agility (Quinn 2010). For 'last mile' deliveries, there are reports of ox-drawn carts being used or volunteers wading through flooded areas to deliver supplies (USAID 2011 and Davis 2010). Also, after the flood in Myanmar in 2008, WFP worked with the Logistics Cluster comprising 39 organizations using common logistics services to distribute first-aid, food items and non-food items to beneficiaries using airplanes, helicopters, boats, all-terrain vehicles, motorcycles and bicycles (Quinn 2010).

b) Information flows: NGOs are using different Information Technologies to improve their humanitarian relief efforts. Besides the use of census data and satellite images of the flood waters spreading in different areas to improve its relief efforts, WFP has utilized mobile phones with smartcards containing beneficiary identification to monitor and coordinate food distribution activities in India (Economist 2010). In addition, WFP is exploring the use of beneficiaries' biometric data (fingerprints, retina scans) to ensure fair food assistance (Yu 2010). Also, information technology such as GIS (Geographical Information Systems) and social media such as Twitter and Facebook can be used to organize local response efforts: Professor Quintus Jett of Dartmouth University described

a community project called MOSAIC New Orleans that enabled 'open-sourced' groups to support the restoration of flood-damaged New Orleans neighborhoods in 2005.[4]

c) Cash flows: An increasing number of international NGOs such as Oxfam and WFP are offering cash, vouchers (virtual cash), or cash-for-work vouchers to beneficiaries so that they can use them to buy food or other essentials. For example, in 2011, Oxfam distributed 1000-rupee (approx. US$10) vouchers to beneficiaries so they could buy foods from designated micro-retailers. Oxfam would then pay these micro-retailers for the cash value of the vouchers (Oxfam 2011).[5]

In some developing countries such as Vietnam and Philippines, cash transactions between micro retailers and beneficiaries can be conducted via mobile money applications on their mobile phones (Ure and Lovelock 2007). For example, WFP distributed electronic vouchers via mobile text messages to registered beneficiaries immediately after a typhoon landed in the Philippines in 2011 so that they could buy food from micro-retailers (Rosenberg 2011). By using mobile phones to conduct these transactions, WFP can reduce time and cost to distribute vouchers while increasing its track-and-trace capability and reducing frauds. Also, beneficiaries can receive these vouchers in a secure and fair manner, and micro-retailers reduce their cash-to-cash cycle.

3.2 Disaster Relief Efforts for Flood Relief

The National Governors' Association (NGA, 1979) lists a four-phase approach to managing disasters: (a) mitigation, (b) preparedness, (c) response, and (d) recovery.

a) Mitigation. Governments play a significant role in mitigating flood risks by identifying areas prone to floods and by preventing development in these areas. Also, governments can reduce flood risks by building dams, reservoirs, dikes, levees, flood channels, and approaches for flood risk management (cf. Schanze et al. 2006). Aligning public and private incentive is necessary to develop policies for reducing social and economic impact of floods. The resulting efforts could be economically beneficial for developments in flood-prone areas such as New Orleans (Loucks et al. 2008).

b) Preparedness. Due to the predictability of timing and location of a flood, the following can be used to prepare for flood relief:

- Beneficiary identification: To ensure that food assistance is distributed to the "right" beneficiaries after a natural disaster such as flood, one can develop identification cards by registering beneficiaries in advance using photos, fingerprints, or biometric information. By doing so, NGOs can distribute food to registered beneficiaries quickly and prevent the issue of multiple registrations and other fraudulent activities.[6]

- Terrain information: Satellite imaging and weather forecasts already exist to identify populations vulnerable to an imminent flood. The next step is disseminating this information. WFP's Emergency Preparedness and Response Web provides publicly available repository geo-referenced databases. These databases enable WFP to develop contingency and emergency plans, and logistic plans for distributing food items especially after a natural disaster (Yu 2010).

- Stock pre-positioning: WFP's Latin America and the Caribbean Emergency Preparedness and Response Network (LACERN) increased its capacity for storing and moving food rapidly within the region by pre-positioning equipment in Panama, and pre-positioning stocks of food and non-food items in Ecuador, El Salvador, and Barbados (Balletto and Wertheimer 2010).

- Coordination: Developing a common 'platform' for information exchange and coordination across different entities is critical for flood relief. For example, the UN Joint Logistics Centre (UNJLC) set up a bulletin service on its website to coordinate logistics activities (Tomasini and Van Wassenhove 2005). Coordination is needed for using scarce transportation resources during floods. For instance, in the 2000 floods in Mozambique, UNJLC managed to increase the number of flights and helicopter utilization across different parties through web-based coordination (Samii and Van Wassenhove 2003).

- Monitoring-and-advance-warning systems: Such systems use control charts to monitor water levels and issue an alert to people in flood-prone areas can be useful. WFP has co-developed an early warning web-based system called HEWS web to present latest bulletins and warnings on possible disasters in Asia, Africa

and Latin America (Balletto and Wertheimer 2010). Text-based flood warning variants can be conceived instead for use in urban areas.

c) Response. Response time comprises: (1) time to detect (and locate) the disruption (e.g., flood), (2) time to design (or prescribe) a solution in response to the disruption, and (3) time to deploy the solution (Olshansky et al. 2012; Sodhi and Tang 2012: Chapter 5).Detection time can be reduced by developing mechanisms to discover a risk incident quickly when it occurs or even to predict it before it occurs. Monitoring and advance warning systems help reduce the detection lead time. Design time can be reduced by improving preparedness so that all affected parties have well established contingent plans in advance as discussed in the previous subsection. Deployment time can be shortened by improving communication and coordination among the different entities, once a recovery plan has been selected. Information and communications technology (ICT) can certainly help in reducing the deployment time, as for example with WFP distributing food vouchers to registered beneficiaries in the Philippines after the 2011 flood using text messages. Yu (2010) describes how WFP uses ICT to deliver food assistance.

d) Recovery. Governments and/or NGOs already leverage the supply chain expertise of the private sector for humanitarian relief especially logistics companies such as DHL (Gupta and Perupu 2008), TNT and UPS. For example, UPS offered the Salvation Army "UPS track pads" to track and help confirm that each affected family received an appropriate amount of critical food and supplies after the Haiti earthquake in 2010 (Lynn 2012). While the private sector has been involved in humanitarian relief, it has not played a critical role in supporting economic recovery after a flood. We believe that a more active private sector would hasten economic recovery because the private sector can help bringing in back jobs that were lost due to floods and restoring businesses that were disrupted by floods.[7]

3.3. Gaps in the Existing Solutions

We find three gaps in the existing solutions: (1) preparedness against floods that occur frequently especially at the 'last mile' areas, (2) response to medium-sized floods that do

not attract the attention of international NGOs or central government but create economic havoc for the people in the affected areas, and (3) recovery of the affected areas.

Firstly, there is a gap in preparedness efforts. As floods are affecting millions of people in many Asian countries, governments seek to strengthen flood defenses and invest in flood warning systems, and international NGOs invest in preparation against massive humanitarian disasters across countries. However, greater attention needs to be paid to preparedness at the 'local' level to ensure people continue to have access to essential goods during a flood. Given the recurrence and the predictable of general floods, such preparedness should be semi-permanent in nature rather than as a one-off event.

Secondly, there is a gap in response as regards 'medium-sized' floods that are not large enough to attract the attention of the international or even national NGOs but these floods are still large enough to disrupt the local economy for extended periods of time. For a massive, say 50-yearflood with the 2% chance of occurrence in a given year, the central government or even international humanitarian relief organizations are likely to be involved in responding to the resulting humanitarian crisis. For a small flood, e.g., a 5-year flood with a 20% of occurrence in a given year, local communities in flood-prone areas have to devise local solutions to assist affected people until the flood waters recede. However, in case of a medium-sized 15-year flood, international or central government humanitarian relief is unlikely to be available. At the same time, local solutions would be inadequate because normal supply chain operations would be disrupted, and relief efforts would require a coordinated region-wide effort possibly involving NGOs, local government and manufacturers of essentially goods. In this case, who should organize the response for medium-sized flood?

Finally, while the effort of various parties to respond to disasters to contain the loss of lives is admirable, there continues to be a gap in solutions for economic recovery especially when the economic disruption and losses occur almost annually. Economic solutions have to be tailored to the local economy. For instance, it is hard to conceive of a standard solution for economic recovery that would apply to both the UK floods of 2012 and the Thai floods of 2011.

As such, we must consider the Asian context before we seek to address these three gaps. In developing countries in Asia, a typical supply chain has large (and small) manufacturers that include indigenous ones as well as subsidiaries of western manufacturers such as Cadbury (acquired by Kraft in 2010), Coca Cola, Pepsi, Procter & Gamble, and Unilever. The next downstream echelon in the traditional supply chain is the distributor, who buys from several manufacturers and sells to wholesalers. Finally, those buying from the wholesalers are primarily small-sized family-owned stores called kiranas in India as well as micro-retailers, i.e., roadside vendors and those selling off handcarts.[8] Our field visits in India revealed such micro-retailers barely make US$5/day for their families – even in expensive cities like New Delhi – selling small packets of drinkable water, cold drinks, cigarettes, small sachets of shampoos, etc. These micro-retailers are especially vulnerable to floods since they are deeply embedded in poor communities, which are especially vulnerable to floods. To make matters worse, any disruption can destroy what little they have. Specifically, the business operation of micro-retailers is disrupted during and after a flood in two ways: (a) the distribution of goods from distributors to micro-retailers is disrupted; and (b) the distribution of goods from micro-retailers to flood victims is difficult owing to 'last mile' considerations.

This supply chain structure provides an opportunity. Besides coordinating with NGOs, local government, and upstream supply chain partners, coordinating with micro-retailers is necessary because these micro-retailers have local knowledge – they play a dominate role in selling basic food and personal hygiene items to meet primary needs before a flood by reaching deep into rural areas.[9] Also, by engaging these micro-retailers in flood relief efforts, they can continue their business operations soon after the flood, which would hasten economic recovery.

4. Proposed Solution

Keeping the aforementioned three gaps and the retail supply chain context in many Asian countries in mind, we now propose a solution: (1) to ensure that the distribution of goods to micro-retailers is not disrupted; and (2) to engage micro-retailers in flood relief efforts in a coordinated manner. Our proposed solution calls for buttressing existing traditional

supply chains by having a "social enterprise" to work with micro-retailers, benefitting from their reach into vulnerable communities with the relief.[10] First we describe the general concept of our proposed solution before examining the issues arising from supply chain operations and relief efforts.

To ensure that the availability of goods to micro-retailers is not disrupted during and after the flood, the social enterprise needs to do the following preparatory activities before the flood:

To begin with, the social enterprise will need earmarked land in order to make temporary use of that space for setting up makeshift warehouses. These warehouses will be used to replenish the inventories for micro-retailers during the flood. Such land use would have to be supported by the local government, for example, by earmarking public land such as parks or school playgrounds for defined periods of time commencing before and ending soon after a flood. Once the emergency is over, the use of makeshift warehouse space would end, but that space would remain earmarked for use in the next flood otherwise there is a danger that it could become a land-grab scheme by different parties including the social enterprise. Note that our proposal is different from land set aside by governments for natural disasters in three ways. Firstly, we would like public (or private) land earmarked before, not during or after, a disaster to allow pre-placing inventory based on the anticipated intensity of the flood. Secondly, these plots of land/warehouse spaces should be small and distributed to allow for easy replenishment of goods to micro-retailers. Thirdly, the actual release of earmarked land by the local government to the social enterprise would be contingent on the anticipated intensity of the flood.

Another preparatory activity for the social enterprise would be to buy goods directly from the manufacturers (or from large distributors) and deliver-and-sell to the micro-retailers, using a temporary supply chain network of makeshift warehouses and flood-appropriate transportation links for express use in the relief effort only just before, during, and just after a flood.[11]

Furthermore, to engage micro-retailers in flood relief, the social enterprise should work with the regional government, manufacturers and micro-retailers to coordinate 'last

mile' effort to distribute essential goods. Specifically, the social enterprise can leverage the traditional retail supply chain that operates during normal times to quickly establish a temporary supply chain involving manufacturers/distributors and micro retailers during the abnormal time around a flood event. After the flood related crisis issues subside, the regular supply chain should take over. By engaging micro-retailers with local knowledge in rural areas, the social enterprise can enable these micro-retailers to resume their business operations soon after a flood.

While there are additional logistics, communication, and coordination costs for establishing and operating the proposed temporary supply chain, buttressing can enable: (1) faster and more effective humanitarian relief because these micro-retailers are already embedded in the community of affected people; and (2) speedier economic recovery by helping the affected micro retailers restore their business operations quickly after a flood.

We now examine our proposed solution through the lens of supply chain flows and disaster relief efforts.

4.1 Supply-Chain Flows

The buttressed supply chain evolves over four stages: (1) before the flood, a regular supply chain comprising manufacturers, distributors/wholesalers, and micro-retailers caters to consumers; (2) just before the flood, a buttressed supply chain with the social enterprise pre-positions inventory; (3) during the flood and the recovery period, the temporary supply chain run by the social enterprise supplies goods; and (4) after the recovery period, the regular supply chain is restored (Figure 5).

Insert Figure 5 somewhere here

For **material flows**, bulk shipping to the social enterprise's makeshift warehouses for prepositioning inventory would be done by road (or other cheap transportation) before the flood. During the flood, logistics providers will supply using helicopters if these warehouses cannot be reached by road. Distributing or selling small quantities of items to

or by micro-retailers during the disruption/recovery period will have to be done using small rubber boats, bicycles, ox-carts or wading through water.

For **information flows**, census data and satellite images of the spreading flood water can be used to calculate the amount of product needed that can be 'pushed' to the micro-retailers (using credit terms) just before the flood occurs. A social-enterprise coordinated replenishment of micro-entrepreneurs can leverage mobile technology to facilitate communication and coordination of various activities especially because mobile phones are ubiquitous in urban as well as rural areas in Asia (Economist 2010).

For **cash flows**, there are three types: Firstly, the social enterprise will need funds or credit to buy goods from the manufacturers to pre-position inventory, to replenish the inventories during and immediately after the flood, and to cover its operating costs. Secondly, the micro-retailer will need credit for one- or two-days' worth of goods from the social enterprise – if he cannot pay, the maximum amount the social enterprise would lose would be, say, two days' worth of sales or about US $10-$20.Thirdly, the flood-victims may become 'beneficiaries' of national or international humanitarian relief efforts. If the government or international NGOs like Oxfam or WFP give vouchers to flood beneficiaries, the social enterprise would ensure that it can take vouchers from micro-retailers, who in turn will take vouchers from the flood beneficiaries in exchange for essential goods. Mobile technology may also be used for cash transactions especially as doing so offers traceability and may prevent price gouging.

4.2 The Disaster Relief Context

We now examine the buttressed supply chain in terms of disaster relief efforts:

Mitigation. The social enterprise has to mitigate two execution risks: trust and funding. Firstly, to ensure that it is trusted by all parties, the social enterprise can be the result of well-established non-government organizations like the IFRC, a local chapter of an international NGO like Red Cross or Oxfam working with 'regionalized' supply chains, or a consortium of manufacturers and/or distributors interesting in moving essential goods to consumers even during floods (Charles et al. 2011). Secondly, if the social enterprise is based on one of these forms, it should have sufficient funds to buy goods

from the manufacturers to pre-position inventory, and to replenish the inventories during and immediately after the medium-sized flood. Moreover, to mitigate the risk of product shortage during the flood, the social enterprise can make "contingent" contracts with the manufacturer (or distributor) in advance according to a pre-specified "n-year flood" plan.

Preparedness. Before the flood, the social enterprise can use historical data to identify vulnerable areas and populations, help the select community to be aware of evacuation plans directly or through its network of micro-retailers. The social enterprise could use monitoring-and-advance-warning systems to monitor water levels and to issue alerts should any anomalies occur. Also, the social enterprise should register the micro-retailers of the select area before the flood and give them 1-2 days of credit during flood times. Also, the social enterprise needs to determine optimal locations for pre-positioning inventory before the flood. The pre-positioned inventory has to be near the micro-retailers so the social enterprise will have to consider multiple small locations contingent upon flood intensity. As regards to coordination, the proposed social enterprise has to work with various organizations (the government, NGOs, manufacturers, logistics service providers, micro-retailers) to define the roles and responsibilities and to improve communication and coordination when responding to flood-induced humanitarian crises.

Response. Once the flood is known to be imminent along with its anticipated intensity, the social enterprise needs to manage its response. The social enterprise reduces design time for the solution as its plans are contingent upon flood intensity and through its communication channels with manufacturers as well as micro-retailers. The social enterprise also shortens deployment time by communication and coordination among supply chain entities including the manufacturers and the micro-retailers.

Recovery. The justification for buttressing supply chains of essential goods is based on faster economic recovery of micro retailers. Moreover, the same benefits accrue to the manufacturers because the social enterprise provides an alternative channel during the disruption period. Because the micro retailer is not economically disrupted, his (economic) recovery is virtually immediate. The wholesalers and the distributors will recover when the buttressed supply chain is disbanded.

5. Quantifying the Benefits Using Stylized Modeling

To quantify the value of buttressing a supply chain for flood relief, we now present a base model of a regular supply chain with its micro retailers located in a flood-prone area. Our focus is on the micro retailers and we are not considering the distributors and wholesalers. First we present a stylized model based on a traditional supply chain (§5.1) and then we analyze the value of buttressing this supply chain (§5.2). The model is simplistic and is intended only to highlight some of the decisions and parameters entailed in the buttressing to provide a basis for further research.

5.1 A Base Case Model of a Traditional Supply Chain

The traditional supply chain in our model comprises one manufacturer selling to independent distributors or wholesalers who sell to K micro-retailers, who in turn sell to poor consumers. The demand D in each period for each micro-retailer is assumed to be independent and normally distributed with mean μ and standard deviation σ. Although there are different 'zones' of flood-proneness depending on the flood intensity, we consider a single zone here for exposition.

Consider the case when a flood occurs on day 0. Assume there is a probability a that a micro-retailer i will be "affected" by the flood in time period 0 so the number of affected micro-retailers N is binomially distributed. For the N affected micro-retailers, assume each is "disrupted" in the same way with probability d on any subsequent day after the flood. Hence, the disrupted duration after a flood T for retailer i is the first day that there is no disruption.[12] Hence, T follows a Geometric distribution so that $P\{T = t\} = d^t(1-d), t = 0,1,2,3, \ldots$, where $E[T] = \frac{d}{1-d}$.

After the flood-related disruption is over at time T, assume that there is a "recovery period" of (θT) days after which the N affected micro-retailers can resume their business operations, where θ>1 is a parameter. This assumption is based on empirical observation that recovery for floods is much longer than the disruption period. None of the N affected micro retailer will have any revenues for $(1 + \theta)\, T$ days after the flood. Hence, the expected total sales loss to all affected micro retailers is equal to $N\,(1 + \theta)\, T\, D$. Taking N

~ Binomial(K, a) and D ~ *Normal*(μ, σ^2)and assuming these random variables are independent of each other, we can compute the expected loss L= E[N($1 + \theta$) T D] to establish the following observation:

Observation 1: Without buttressing the supply chain, the expected total loss in sales to the micro retailers after a flood is$L = Ka(1 + \theta)\frac{d}{1-d}\mu$, so that L increases with the disruption probability d.

When relief agencies donate and distribute goods to the affected, these relief efforts reduce the need for the villagers to buy certain products from micro retailers after the flood. Despite good intentions, these relief efforts can actually undermine the business and prolong economic recovery of the micro retailers (Oxfam 2011).[13] As such, losses to micro-retailers may be more than those suggested by Observation 1.

5.2 Modeling a Buttressed Supply Chain and Evaluating its Value

A buttressed supply chain that involves social enterprises can be established quickly and operated on a temporary basis. The social enterprise would need to determine the amount of inventory to pre-place at those makeshift warehouses to enable the social enterprise to supply each affected micro retailers during the disruption period T. However, because T is a random variable, it is practical for the social enterprise to first set a "target coverage period" τ and then determine the corresponding inventory level to be pre-placed. An immediate question is: How should the social enterprise determine the target coverage *period τ?*

To determine τ; it is convenient to evaluate the target τ based on its associated risk P{$T>\tau$}; i.e., the probability that micro-retailers' operations will be disrupted even with buttressing in place. Suppose we measure this "risk profile" associated with τ according to 1/m so that $P\{T > \tau\} = \frac{1}{m}$, where m is an auxiliary variable derived directly from τ. T is geometrically distributed so$P\{T > \tau\} = \sum_{t=\tau+1}^{\infty} d^t(1-d) = d^{\tau+1}$and $\frac{1}{m} = d^{\tau+1}$. By taking logarithm and by noting that$d < 1$and $\log(d) < 0$, we can transform our decision variable from τ to m by using:

Observation 2: When operating the buttressed supply chain with risk profile 1/m, the *corresponding target coverage period* τ is given by $\tau = \frac{1-\log(m)}{\log(d)} - 1$, where τ is increasing d and m. Note that $\tau > 0$ if and only if m > 1/d.

We focus on the case when m > 1/d so that the target coverage period $\tau > 0$ in the remainder of this section. Noting that the number of affected micro retailers N ~ Bi(K, a), each of which faces per period demand D ~ *Normal*(μ, σ^2), the amount of inventory to be pre-placed by the social enterprise associated with the target coverage period τ is equal to E[N $(1 + \theta)\ \tau$ D] so that:

Observation 3: When operating the buttressed supply chain with risk profile 1/m, the amount of pre-positioned inventory to be placed by the social enterprise is equal to $Ka(1 + \theta)\tau\mu$, where $\tau = \frac{1-log(m)}{log(d)} - 1$.

The above observation is based on the expected demand μ without accounting for demand uncertainty captured by the standard deviation σ. If demand uncertainty is high, we can add safety stock to guarantee certain service level. In that case, the amount of inventory to be pre-placed by the social enterprise with risk profile 1/m is equal to E[N $(1 + \theta)\ \tau$ D] + $k\sqrt{Var(N\ (1\ +\ \theta)\ \tau\ D)}$, where k is the safety factor. By using the fact that $Var(XY) = [E(X)]^2 Var(Y) + [E(Y)]^2 Var(X) + Var(X)Var(Y)$ for independent random variables X and Y, we can determine the corresponding inventory for the social enterprise easily; we omit the details. To quantify inventory, we use days of inventory as a metric that is commonly used in practice.

When the temporary supply chain adopts a plan based on the risk profile of 1/m, the social enterprise will pre-place its inventory so that each affected micro retailer will be able to continue their business operations if $T \leq \tau$; hence, the effective disruption period for each affected micro retailer is equal to max{(T – τ), 0}. Therefore, the temporary supply chain will reduce the disruption period for each affected micro retailer from T to max{(T – τ), 0}. Because T ≤max{(T – τ), 0} for any realization of T, we can conclude that E(T) ≤ E[max{(T – τ), 0}]. Also, the expected effective disruption period satisfies:

$$\mathrm{E}(max\{(T-\tau),0\}) = \sum_{t=\tau+1}^{\infty}(t-\tau)d^t(1-d) = \frac{d^{\tau+1}}{(1-d)} = \frac{1}{m(1-d)}.$$

The last equality is due to the fact that $\frac{1}{m} = d^{\tau+1}$.Note that the expected effective disruption period is increasing in the disruption probability, d.

By establishing a temporary supply chain using social enterprises, the effective total loss in revenues to the micro retailers is

$$L' = E[N(1+\theta)\,(max\{(T-\tau),0\})\,\mathrm{D}].$$

Noting that N ~ Binomial(K, a), D ~ *Normal(μ, σ^2)*, and the random variables are independent, we have:

Observation 4: With the supply chain buttressed with a social enterprise, the expected total loss in sales to the micro-retailers after a flood is

$$L' = Ka(1+\theta)\frac{d^{\tau+1}}{(1-d)}\mu = Ka(1+\theta)\frac{1}{m(1-d)}\mu.$$

Comparing Observations 1and 4, it is clear that $L' < L$ when $\tau > 0$ (i.e., when we set m > 1/d as in Observation 2),and $L' = L$ when $\tau = 0$so the temporary supply chain operations can help reduce the expected disruption period and the expected loss in sales to the affected micro retailers.

We now determine the optimal risk profile by determining m* that maximizes the economic benefit of the temporary supply chain for humanitarian relief and economic recovery. Once we determine m*, we can apply Observation 3 to retrieve the corresponding optimal τ*. Suppose the unit cost for having the social enterprise to purchase, pre-place, and handling each unit of inventory at the makeshift warehouse is equal to c, and suppose the profit margin for micro retailers to sell each unit after the flood is equal to r. Then we can apply Observations 1, 4 and 5 to show that:

(1) The total expected cost for the social enterprise to handle the pre-placed inventory is equal to $cKa(1+\theta)\left(\frac{\log\left(\frac{1}{m}\right)}{\log(d)} - 1\right)\mu$, and

(2) The total expected savings due to reduction in sales loss is equal to r(L – *L'*)

$= rKa(1+\theta)(\frac{d}{(1-d)} - \frac{1}{m(1-d)})\mu.$

Therefore, the expected economic benefit of establishing a temporary supply chain using social enterprise is equal to

$$B = Ka(1+\theta)\mu\left[r\left(\frac{d}{(1-d)} - \frac{1}{m(1-d)}\right) - c\left(\frac{\log\left(\frac{1}{m}\right)}{\log(d)} - 1\right)\right].$$

By differentiating B with respect to n and by considering the first order condition, we can determine m* and then we can retrieve optimal τ* using Observation 3, getting:

Observation 5: The optimal m* that maximizes the expected economic benefit associated with a buttressed supply chain B satisfies: $m^* = \frac{r\log(\frac{1}{d})}{c(1-d)}$, where m* is increasing in the disruption probability d. Consequently, $\tau^* = \frac{1-\log(\frac{r\log(\frac{1}{d})}{c(1-d)})}{\log(d)} - 1.$

The benefits associated with the buttressed supply chain (in terms of reduction in disruption period, reduction in sales loss, etc.) would be even more if we account for the resulting bullwhip effect.

6. Conclusions and Future Research

We have proposed a temporary supply chain to buttress traditional supply chains in Asia that get disrupted during floods. Our solution involves a social enterprise for humanitarian relief and economic recovery caused by a flood. By using a stylized model, we have argued how all entities in the supply chain including consumers would be better off if a social enterprise were to deliver essential goods to micro-retailers just before, during, and just after a flood. Although our work builds on existing efforts of humanitarian organizations, much work remains to be done by way of future research:

1. Innovative business models for social enterprises to deal with humanitarian efforts against floods and other disasters in a temporary supply chain setting.

2. Incentives of the different bodies – not just the supply chain entities but also the central and regional governments, NGOs, and relief agencies – to work together for the buttressed supply chain.
3. Looking at the state-of-the-art hydrological literature on detecting floods and marking different regions with vulnerability to floods of different intensity.
4. Land use policies for different types of land developments at different levels of flood intensity (e.g., Wheater and Evans 2009).
5. Earmarking public land/warehousing space contingent on the expected timing and intensity of annual floods along with use of satellite images.
6. Identifying multiple and small locations contingent on flood intensity for pre-placement of inventory and other assets including floods-appropriate transportation.
7. Pricing and incentives to ensure that the buttressing is temporary and so that micro retailers will switch to wholesalers after the recovery period.
8. Contracts between the social enterprise and the manufacturers that are contingent upon the observed flood intensity.
9. Extending our stylized modeling by incorporating multiple zones of different flood intensities, by refining the model on costs and benefits, by being cognizant of the hydrology literature as well as the topography of different regions and terrains.
10. Case studies of flood-related disasters as well as humanitarian relief in these disasters.

Humanitarian supply chains for flood disasters provide an increasingly important OM research opportunity that can benefit from existing humanitarian efforts and initiatives as well as research in fields as diverse as the civic society literature and hydrology. We hope we have whetted research appetite by presenting the 'problem' of floods in Asia, by highlighting elements of existing humanitarian supply chain efforts, by identifying a gap in these efforts and by outlining a possible 'engineering' solution for this gap.

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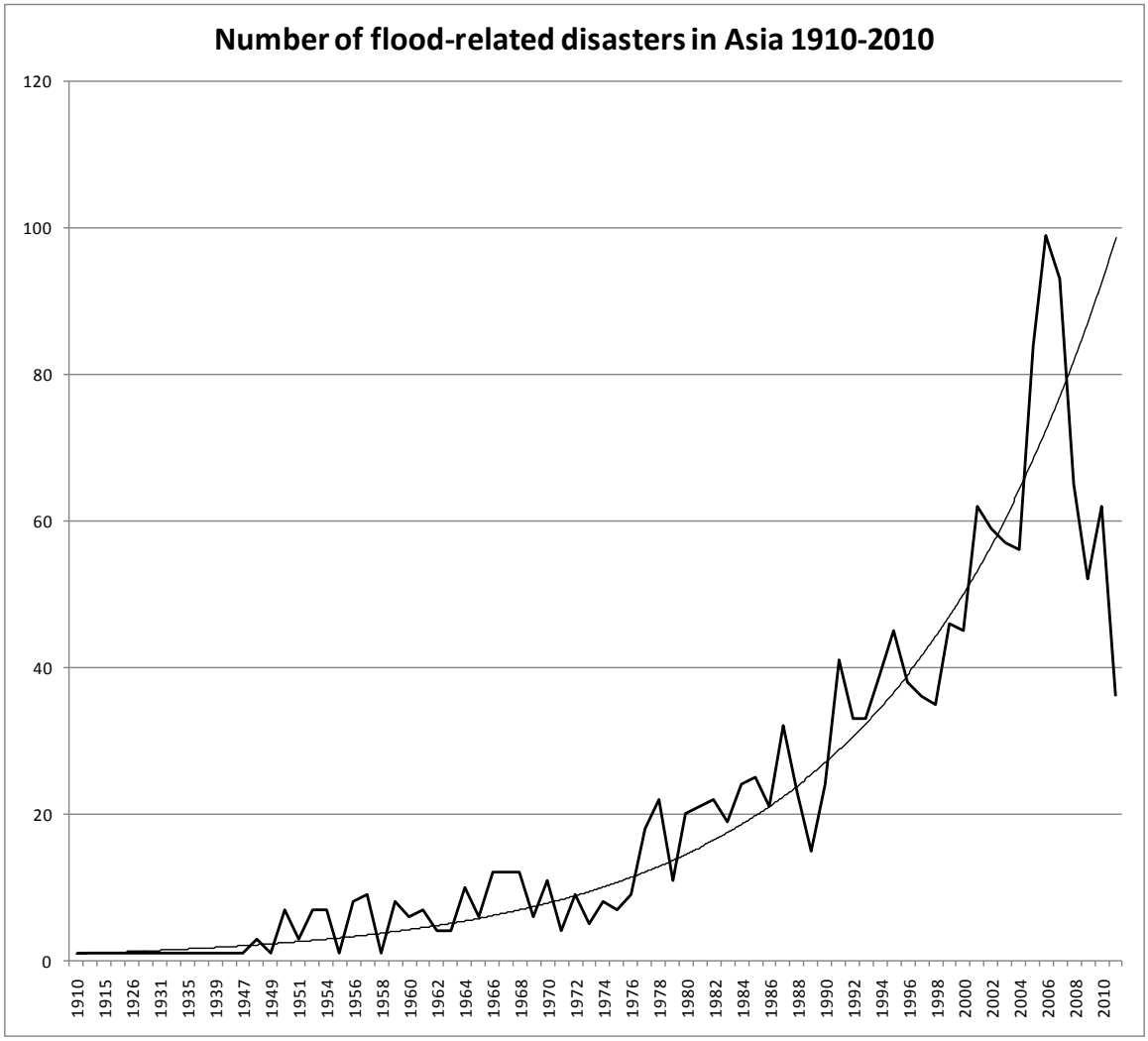

Figure 1: Number of floods in Asia over the period 1910-2010 with an exponential trend line (Source: EM-DAT database from CRED, www.emdat.be, query run on 30th March, 2012 on database version 12.07)

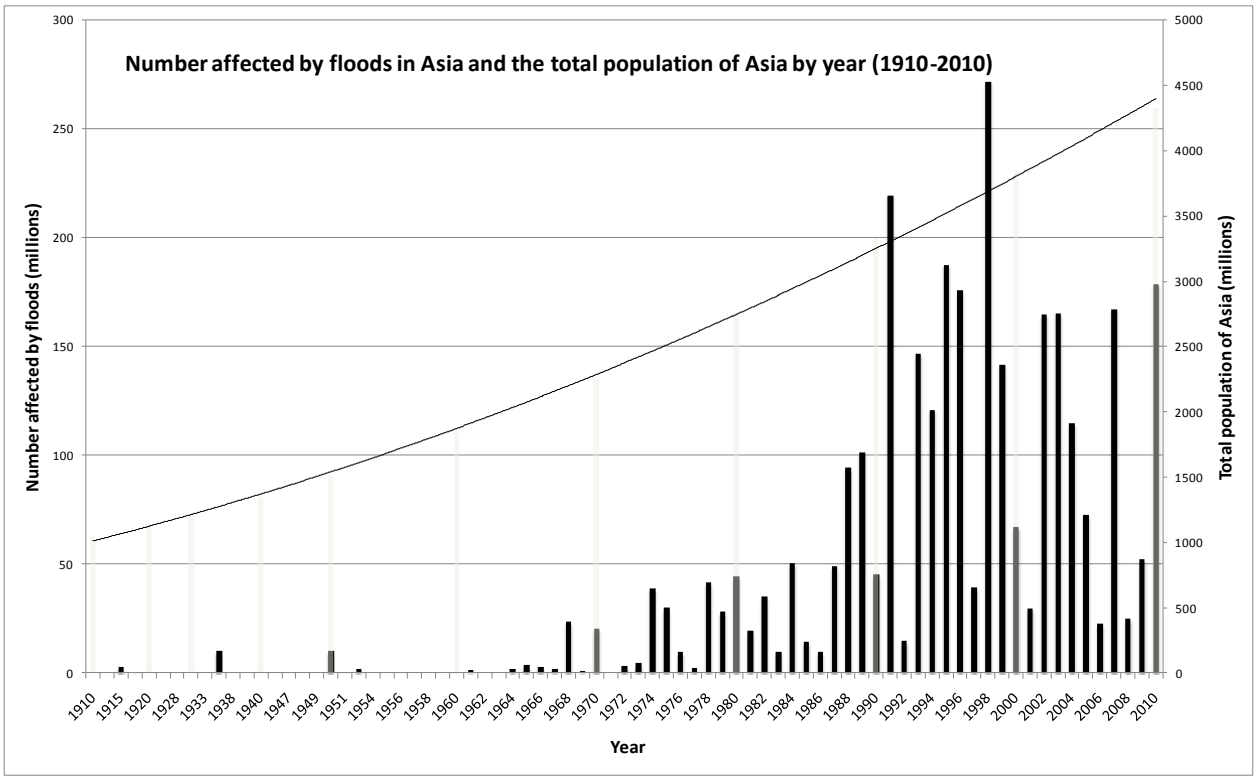

Figure 2: Number of people affected by floods in Asia each year (left axis and bars) and the total population of Asia by year (right axis and trend line) (Source: EM-DAT database from CRED, www.emdat.be, query run on 28th April, 2012 on database version 12.07); there are some gaps in the floods data prior to 1955; population data is from Wolfram.

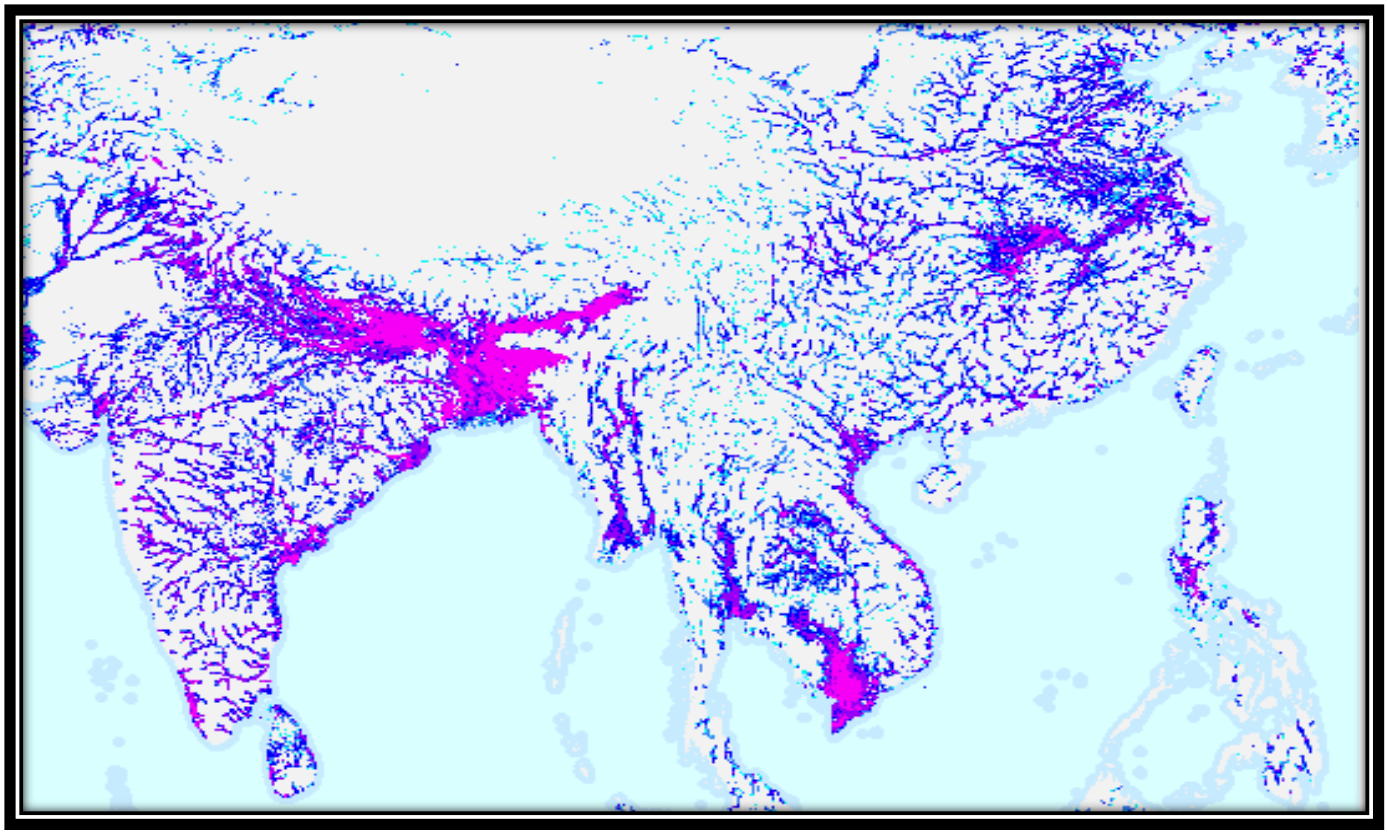

Figure 3: Asian flood risk in 2011 (darkened areas are high risk areas). (Source: OCHA (United Nation Office for the Coordination of Humanitarian Affairs)

Figure 4: Logarithm (base 10) of total number of people affected every year in India and Indonesia; in most years during 1980-2011, hundreds of thousands (10^5) were affected in Indonesia and tens of millions (10^7) in India. (Source: EM-DAT: The OFDA/CRED International Disaster Database, www.emdat.be, query run on 30th March, 2012 on database version 12.07)

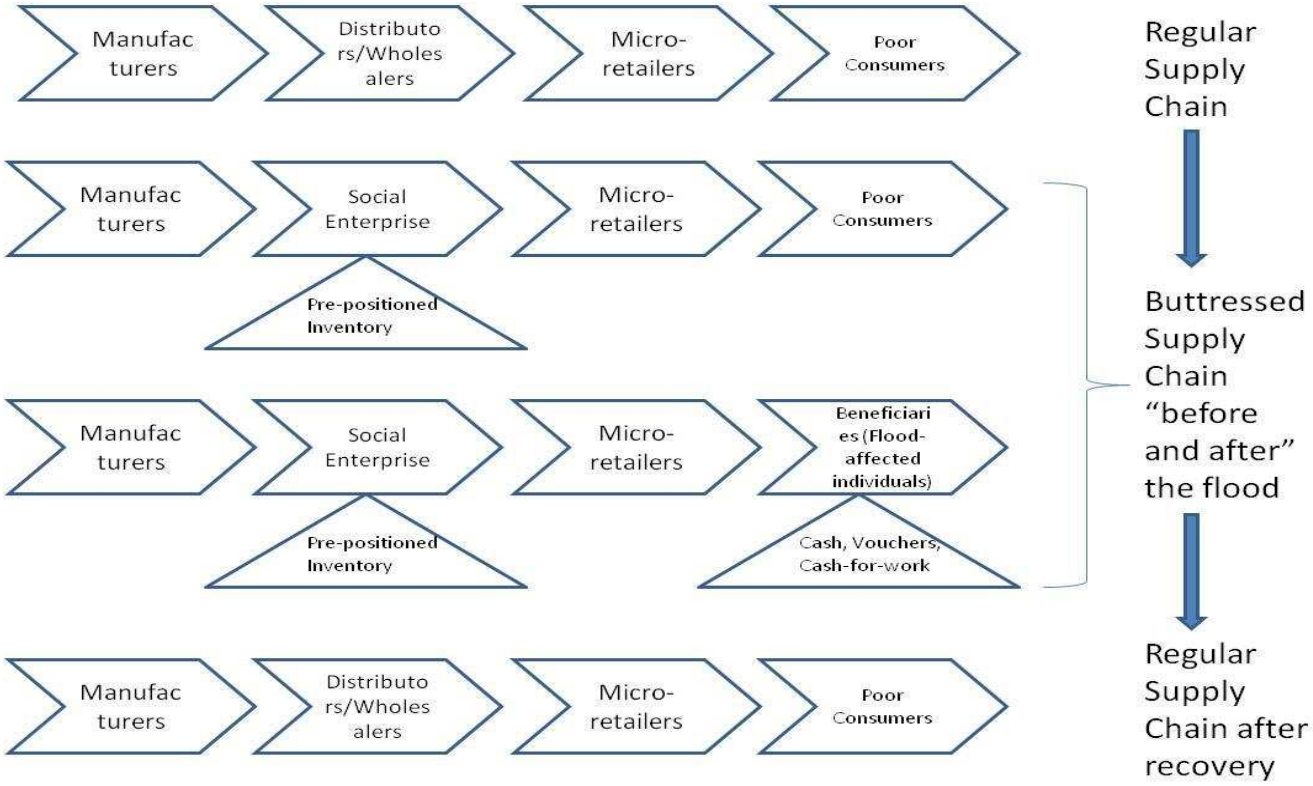

Figure 5. Buttressing a regular supply chain for improving the relief and recovery operations associated with a flood.

Notes

[1]We use the term *buttressing* motivated by the buttressing, or strengthening of levees, during floods.
[2]Micro-retailers are small, independent, family owned businesses in developing countries. In India, micro-retailers account for over 90% of the retailing industry that involve over 40 million Indians.
[3]An "*n*-year flood" is a measure of the "size" of a flood. For example, a 100-year flood is calculated to be the level of flood water expected to be exceeded once in 100 years ((Holmes and Dinicola 2010). Thus, a 100-year flood corresponds to a 1% chance, the right-tail probability of the historical distribution of annual flood levels, that the level of flood water in any single year will exceed the level represented by a 100-year flood. Assuming each year to be independent as regards flood level, even two consecutive years may experience 100-year floods.
[4]See a video at http://digitalstrategies.tuck.dartmouth.edu/media-library/radiotuck/open-source-organizing/
[5]In the Sahel region of Africa, WFP managed to continue and integrate the vouchers into local market systems in 2006. To prevent price gouging during floods, there are over 478,000 fair-price shops in various villages throughout India. India already uses "Maximum Retail Price" printed on the items.

[6]In India and the Philippines, the beneficiary identification data can be stored in smartcards so that the relief workers can utilize mobile phones to distribute food, cash, vouchers, etc. after the flood.

[7]Jose Holguin-Veras discusses the cooperation between major donors and local collaborative networks – these include churches and other local 'network' organizations – based on his experience in Chile and Haiti in 2010 earthquakes. See:
http://www.youtube.com/watch?gl=GB&v=0gGxNSqwOX4.
[8]While international retailers like Carrefour, Tesco, and Wal-Mart, as well as indigenous ones like Mother Dairy and Reliance are expanding slowly in India, the informal retail sector remains important even in developed economies like Korea.
[9]During the Thai floods of 2011, many communities were short of many essential goods. Consequently, the Thai government announced the need to import three categories of goods: (1) drinking water and food items such as canned fish, eggs, sweetened condensed milk, soybean milk, UHT milk, instant noodles, instant foods, and fresh vegetables; (2) consumer products such as sanitary napkins, toilet paper, soap, toothpaste and toothbrushes; and (3) water purifiers and drinking water vending machines (MCOT, 2011). Other items include blankets, bed nets, and other ready to use supplementary food such as high-energy biscuits (HEB).
[10]According to the UK Department of Trade & Industry, a social enterprise is a business with primarily social objectives whose surpluses are principally reinvested for that purpose, rather than being driven by the need to maximize profit for shareholders and owners. (DTi, 2002, p. 7)Such an enterprise can take one of many legal forms. For instance, in the UK, their legal status could be Community Interest Company, Company Limited by Guarantee, Company Limited by Shares, or an Industrial or Provident Society. Many also take charitable status. In practice, they may be cooperatives, credit unions, housing associations, community development trusts, social firms, and community businesses (SEL, 2012).

[11]The notion of pre-positioning food and non-food items at designated logistics hubs for enhancing preparedness of humanitarian relief operations in Latin America and the Caribbean has been implemented in 2007 by WFP. The reader is referred to Balleto and Wertheimer (2010) for details.
[12]Here, all affected retailers are subject to the same disrupted duration T; however, the same approach can be used to analyze the case when different affected retailers i have different disrupted durations, T_i.
[13]USAID, a US relief agency, created controversy in 2002 by offering African countries genetically modified corn; this was opposed on grounds it would 'contaminate' the local seed and make African farmers dependent on a few large companies providing the seeds of genetically modified corn (BBC, 2002). Thus, economic recovery could never be complete. See also Van Wassenhove and Tomasini (2004).