

3.6. Climate Change and Trade Networks

Contributed by Nicole Glanemann, Sven N. Willner and Christian Otto

As indicated in Part 2 of this report, extreme weather events are projected to become more frequent and intense under climate change. A sharply rising trend in the costs incurred locally by extreme weather events can already be observed today (Ward and Ranger 2010). Extreme weather events can wreak havoc on a company's supply chain, shutting down its production facilities or preventing its suppliers or logistics providers from fulfilling their commitments. These production losses occur abruptly and are difficult to anticipate. Moreover, the resulting supply shortages can propagate through the globalized network of supply connections (hereafter "trade network") leading to cascading losses (Levermann 2014). Hence, the economic impacts of local extreme events are by no means confined to national boundaries but might have repercussions not only across the Asia and Pacific region, but across the globe. For example, droughts in the United States, the Russian Federation, and Australia; floods in Thailand; and typhoons in the Philippines in recent years have resulted in production losses and steep price increases globally for a wide range of goods ranging from wheat to computer chips (The Economist 2012).

Although firms implement local adaptation measures tailored to their respective supply chains, it is unknown and uncharted how the different strategies interact with each other and affect global supply networks. Recent extreme weather events experienced in the region indicate that existing company-specific measures taken to date are not sufficient to mitigate supply shortage cascades. Accordingly, several countries have initiated efforts to design strategies for increasing the resilience of the regional supply chains (White House 2012).

Nowadays, resilient supply chains are of extreme strategic importance to maintain economic competitiveness and are expected to become even more important in the future (Christopher and Peck 2004; Lee 2004; Sheffi and Rice 2005). Well-designed adaptation strategies are particularly important for most countries of Asia and the Pacific, as their economic development and growth significantly depends on trade. Increased world market integration will also expose them to systemic risk of cascading supply losses. As companies in developing countries might lack the capacities to develop adaptation strategies, public sector policies can play a crucial role in supporting them and setting adequate incentives for managing this risk in an optimal way (IPCC 2014). As cascading production losses do not respect national borders, national policies have to be well coordinated or developed in multilateral efforts.

This section first demonstrates the potential impacts of disaster-induced production losses traveling along the supply chains in Asia and the Pacific. Then, we summarize the main factors contributing to an increased vulnerability of the global supply network and refer to possible adaptation measures that may

alleviate these vulnerabilities. Eventually, we conclude by identifying the research needed to single out policy-relevant, suitable adaptation concepts.

Assessing the Climate Impacts on the Asian Supply Chains

As discussed earlier in Part 2, recent studies reveal that flood risk is projected to increase significantly in Southeast Asia and India under global warming. Since industries in this region are highly interlinked, localized disasters may have transnational repercussions.

Research on the impacts that extreme weather events can have on the global trade network is at its very beginning. Transmission of production losses through the input–output linkages between firms has been identified as a key mechanism that has the potential to make small, localized production shocks snowball into macroeconomic downturns (Acemoglu, Ozdaglar, and Tahbaz-Salehi 2014; Gabaix 2011). The likelihood and duration of such a loss cascade depend on certain properties of the affected parts of the supply network such as the range, connectivity, and trade volumes of the disturbed supply chains (Acemoglu et al. 2012; Wenz and Levermann 2016).

Based on these insights, Glanemann et al. (2016) develop a measure of the production shortage interdependency (PSI) between countries (Box 3.4). This measure can be used to identify the degree to which national economies are connected with some other country, and thus are potentially vulnerable to disaster-induced production shocks in this country. For example, a reduction of India's exports directly affects production in the PRC and many other Southeast Asian countries, unless the direct trade partners are well prepared to respond to possible supply shortages (Figure 3.16, left column, top panel). Production shortages in those countries might then cut down their trade partners' production. Apart from a few least developed countries, this secondary impact affects all countries worldwide (Figure 3.16, left column, bottom panel).

PSI also quantifies the state of some countries' import dependencies. For example, India's production is contingent on the direct imports from economically thriving countries like Australia, Canada, the PRC, Japan, and the United States (Figure 3.16, right column, top panel). These countries' production, however, also depends on some other countries' exports. Taking these indirect effects into account, it is then found that India's production is also reliant on other highly vulnerable countries like Indonesia and Thailand (Figure 3.16, right column, bottom panel).

This static analysis shows that the developing countries in Asia might hamper each other's economic growth in a changing climate with more frequent and more devastating weather extremes.

A dynamic analysis providing insights into the propagation of supply shortages is offered by the trade network simulation model Acclimate (Bierkandt et al. 2014; Wenz et al. 2014; Otto et al. 2016). The model describes the immediate response of the global economy to local disasters as well as its recovery dynamics in the disaster aftermath. Furthermore, price effects, which are important to assess the losses of large-scale disasters, can be analyzed. This renders the model well-suited for the assessment of the loss avalanches of unanticipated disasters. Acclimate can be also used to assess global adaptation options in future research.

Box 3.4: Estimating Production Shortage Interdependencies

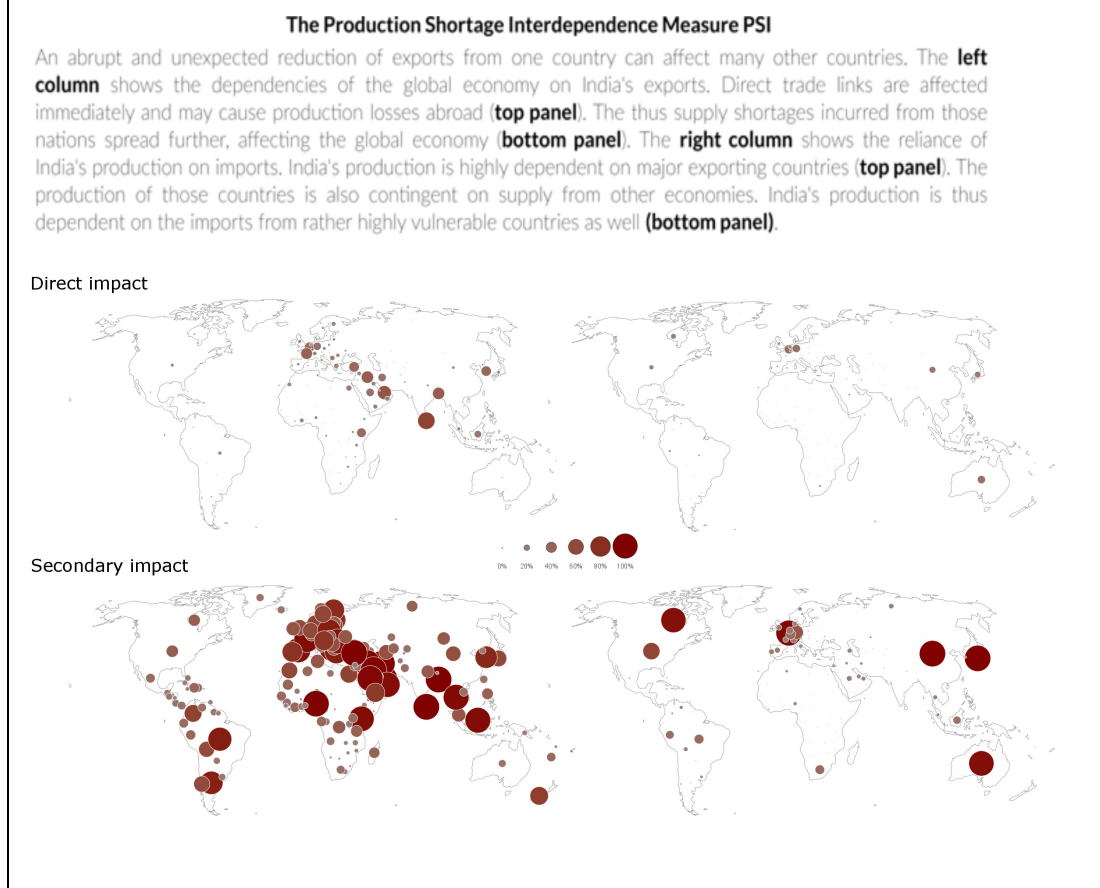
The analysis of potential supply chain cascades is conducted by the network measure production shortage interdependency (PSI; Glanemann et al. 2016) and the dynamic supply network model Acclimate (Bierkandt et al. 2014; Wenz et al. 2014; Otto et al. 2016).

PSI belongs to the class of centrality measures determining the importance of one vertex, or producer, for the rest of the network to be functional. The index assesses and tracks the input dependence of other producers on a particular supplier from one supply chain layer to the next. Thereby, PSI allows for alternative assumptions on the substitutability of the scarce inputs. The illustrations of the potential production shortages (see Figure 3.16 of this report) are based on the assumption that substitutability is rendered difficult or even impossible, which may be the outcome of an extreme weather event. The unexpectedness of extreme weather events limits the time to reorganize supply and to prepare for supply shortages. The capability to reorganize supply is furthermore limited the more the producers rely on lean production practices. The greater the substitutability of the inputs, the smaller the production shortage dependencies.

Acclimate is an agent-based network model that simulates decisions and interactions by consumers and producers in the aftermath of a production shock. On the same time scale as the local events, the model explores immediate response dynamics as well as the subsequent recovery phase of the economic network. On a daily timescale, each agent optimizes its purchase, demand distribution, as well as production and supply distribution to maximize its revenue. Unlike general equilibrium models, it puts a focus on short-term disequilibrium effects and resolves the transition dynamics toward a new post-shock equilibrium. Thus, it can be used to analyze short-term effects inaccessible by equilibrium-based modeling approaches.

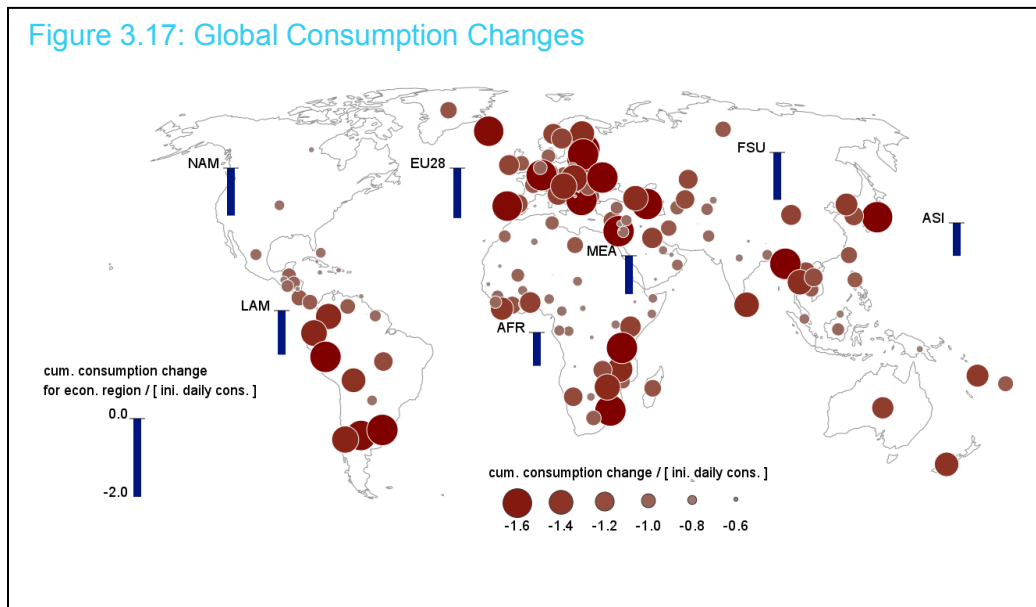
Sources: R. Bierkandt et al. 2014. Acclimate - A Model for Economic Damage Propagation. Part 1: Basic Formulation of Damage Transfer Within a Global Supply Network and Damage Conserving Dynamics. *Environment Systems and Decisions*. 34(4). pp. 507–524; N. Glanemann et al. 2016. *Abrupt Events and the Global Supply Network: A Novel Measure for Cascading Production Losses*. Potsdam: Potsdam Institute for Climate Impacts Research; C. Otto et al. 2016. *Modeling Loss-Propagation in the Global Supply Network: The Dynamic Agent-Based Model Acclimate*. Potsdam Institute for Climate Impacts Research; L. Wenz et al. 2014. Acclimate - A Model of Economic Damage Propagation. Part II: A Dynamic Formulation of the Backward Effects of Disaster Induced Production Failures in the Global Supply Network. *Environment Systems and Decisions*. 34(1). pp. 525–539.

Figure 3.16: Production Interdependencies Illustrated for India in 2011



Assume an unforeseen and abrupt production reduction by 10 % in the Japanese machinery sector. Figure 2 depicts the resulting cumulative consumption changes as a function of time for Asia excluding Japan (gray dashed line) as well as for selected Asian economies. The production in the Japanese machinery sector is reduced for 20 days, which is highlighted by the gray shaded area. Since the Japanese economy is a major exporter of machinery products, reduced Japanese exports result in a global shortage of machinery, triggering price increases in the disaster aftermath. Higher prices reduce national consumption indicating losses in welfare. Asia's economy is strongly affected, due to the tight economic connections between Japan and most other Asian economies. Differences in consumption changes among the individual countries result from the different scarcities they perceive. The magnitude of the scarcities incurred crucially hinges on the dependence on Japan's machinery sector for supply and the capability of the affected production facilities to obtain the missing inputs from other suppliers. As these properties are of such importance, future extreme weather impacts on the Asian supply chains should ideally incorporate projections on the extreme weather events as well as on the developments of the trade network.

Tracing consumption changes back to natural catastrophes (in other countries) that take effect through specific transmission channels is the subject of ongoing research. Studies of the 2011 Tohoku earthquake and tsunami provide some first attempts of quantification. It was shown that permanent energy supply problems led to a contraction of production and persisting supply shortages in Japan (Schnell and Weinstein 2012). As a consequence, consumption product availability decreased by 17% in Japan in the 2.5 weeks after the tsunami (Cavallo, Cavallo, and Rigobon 2014). Cavallo, Cavallo, and Rigobon (2014) report that prices of consumption were relatively sticky in the weeks following the tsunami. They conjecture that prices were largely kept stable to avoid consumer anger directly after the catastrophe and products out of stock are naturally not repriced. The study, however, finds price increases after some months at the time when stocks were replenished. These price increases reversed the deflation trend that existed before the earthquake. The authors find the same qualitative results for the 2010 earthquake in Chile. These statistical findings are to be incorporated into modeling methodology to improve quantitative projections for the future.



Factors Contributing to Supply Chain Vulnerability

There are a number of factors contributing to the vulnerability of an economy to extreme weather events. To reach maximum competitiveness, it was considered good practice to eliminate as many cost inefficiencies in production and along the supply chain as possible (Krafcik 1988; Wee and Wu 2009). With this goal in mind, several concepts have been developed. First, there is the practice of reducing the supplier base, which allows for quantity discounts and high quality assurance (Presutti 1992; Swift 1995; Treleven 1987). This comes with the drawback that failure of one of the suppliers might cut down production significantly. Moreover, redirecting demand to some new supplier might be costly or even

impossible at short notice. Second, there is the concept of just-in-time production, which enables cost saving by reducing or even eliminating inventory holding (Golhar and Stamm 1991; Lee and Ebrahimpour 1984). Just as with the reduction of the supplier base, this measure increases the dependence on timely deliveries by the suppliers. Third, production has become increasingly fragmented—that is, production has been split into many stages outsourced to countries that allow for less cost-intensive production (Holcomb and Hitt 2007; Quinn and Hilmer 1994). As result of outsourcing and of the technological progress in transportation and communication, supply chains have been widely globalized: this globalization can certainly be considered one of the vehicles for many East Asian countries' economic development in the last decade. However, fragmentation and globalization increased the opaqueness of supply chains. Nowadays, supply chains are complex networks that render it difficult to monitor potential risks from the beginning of the production chain to one's own production facility (Goldin and Mariathan 2014).

Possible Adaptation Measures

The measures eliminating cost inefficiencies increase the risk of being incapable to counteract approaching supply shortages in a short time. Acknowledging this problem, experts argue that partially reversing some of the costsaving processes, particularly the reduction of inventory holding and the reliance on a small supplier base (Sheffi and Rice 2005), would enhance the resilience of the global economy. Sharing information about potential bottlenecks with business partners might provide further insights for redesigning the trade connections (Wakolbinger and Cruz 2011). Experts also recommend making production more flexible allowing a greater substitutability of the inputs (Tang and Tomlin 2008; Sheffi and Rice 2005). Moreover, emergency plans that incorporate means to redirect demand to other suppliers at short notice are advocated (Tomlin 2006).

It is not clear whether the private sector's adaptation efforts increase the supply chain's stability and resilience sufficiently. Vague supply chain disruption risk assessments render it difficult to weigh the goal of becoming increasingly cost-efficient against being capable to respond to supply chain disruptions. The opaqueness of the supply network and missing information on potential risks cause the risk assessments to be imprecise. Furthermore, the adoption of measures to increase responsiveness to supply chain disruptions might involve costs that many producers in developing countries cannot afford.

As repeated supply chain disruptions hamper economic growth, it is also in the public sector's interest to design a strategy that reduces supply chain vulnerability and to intervene if the private sector's adaptation efforts do not suffice. Several possible measures are suggested by the United States National Strategy for Global Supply Chain Security (White House 2012). The public sector can modernize and climate-proof important public supply chain infrastructure to prevent supply chain disruptions at the very outset. To promote climate-proofing of private production facilities, the public sector can support building projects serving as role models. It can give recommendations, run programs, set standards, or implement laws for

specific building measures. To help firms in conducting supply chain risk assessments, the public sector can provide information on possible risks and enhance information-sharing practices. To support a fast and efficient recovery after a disruption, it can provide information about best practices. Regarding all efforts, collaboration with the private sector is advised to synchronize measures. As supply chain disruptions can spread across national borders, the public sector also should collaborate with foreign stakeholders and foreign policy makers playing important roles for supply chain operations. Thus, information sharing across borders can be enhanced. Furthermore, international collaboration facilitates the development and implementation of international standards, programs, and guidelines regarding stability and resilience of the global network.

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