Building Supply Chain Continuity Capabilities for a Post-Pandemic World

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Abstract

We frame the supply chain disruptions caused by disasters as a tradeoff between continuity and competitiveness and adopt a capability-based approach to managing this tradeoff. We argue that firms should work to develop *protective, recovery*, and *substitutive* capabilities to change flexibly and quickly between a competitiveness-first focus in "normal" times to a continuity-first focus amid a disaster. We model shifts in performance frontiers made possible by investing in these capabilities and show how firms can move to superior performance vis-à-vis both supply chain continuity and competitiveness. A Disaster Capability Map with examples of all three capabilities is substantiated by a detailed case study of Toyota's overall approach to disaster management and by mini-cases of other Japanese companies adapting to COVID. In conclusion, we challenge three ideas receiving heightened attention in the midst of the pandemic: 1) Just-in-case buffers and dual sourcing; 2) Unilateral localization; and 3) Increased business continuity planning (BCP).

Keywords: Supply chains, disasters, capabilities, protection, recovery, substitution, COVID

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Introduction

The purpose of this article is to highlight the conceptual and practical dimensions of the tradeoff between supply chain continuity and supply chain competitiveness and the organizational capabilities that are required for advancing the performance frontier in the era of COVID-19, an "invisible/global" disaster that differs in important ways from the "visible/regional" disasters familiar from recent years. We adopt an integrated perspective of industrial disaster management, defined broadly to include not only biological disasters like the COVID-19 pandemic but also various physical disasters causing massive destruction such as earthquakes, flooding, and fires, among others. This allows us leverage experiences and knowledge from not only past pandemics but also histories of various disasters that have threatened to destroy local/regional industries and regional/global supply chains.

This special issue of JOM is devoted to highlighting the new practices of logistics and supply chain management deployed during the COVID-19 pandemic and uncovering the key success factors and lessons from these practices. A specific goal is "to understand how innovations in collaboration mechanisms and methods of operations improvement/optimization help companies enhance responsiveness, resilience, and restoration (3Rs) in supply chains… [and] …. how the 3Rs can advance a firm's sustainable competitive advantage in the marketplace" (Call for Papers).

We believe this approach is well-aligned with our broad framework, i.e., a capability-based approach to how firms can pursue supply chain continuity and competitiveness ***simultaneously*** via ambidextrous switching between "continuity-first" and "competitiveness-first" modes of supply chain management. We emphasize three key capabilities: 1) *Protective capability* – to protect a supply chain amid threats of disruption via both preparatory and adaptive action; (2) *Recovery capability* – to bring disrupted sites or routes back on-stream; and 3) *Substitutive capability* – to shift production or routing to other sites or geographies based on pre-identified substitutes.

We developed this approach after studying global supply chains for many years, primarily in the global automotive industry. The auto industry is often a bellwether, with product development, operations, and management practices from this "industry of industries" (Peter Drucker) often having an outsized effect on other sectors. Furthermore, all three of us were in Japan during the March 11, 2011 Tohoku earthquake and tsunami and have examined closely how Japanese firms responded to that incredibly destructive visible/regional disaster. While the impact of this event affected supply chains worldwide, the immediate and immense challenge was faced by Japanese firms that had to make urgent decisions about recovery and substitution. Despite the devastation, most supply chains were operable again within two weeks.

Lean production, derived from the Toyota Production System, argues for geographic proximity, shorter lead-times, and no-more-than-functional buffers (as explained below) to avoid excessive inventory that can hide problems and block learning. Disasters that interrupt supply chains frequently stimulate calls to reexamine the value of lean buffers in favor of higher "just-in-case" inventory levels and moving from single to dual sources. In addition to increasing buffers as a disaster response, another frequent proposed remedy is shifting from global to local production networks and supply chains. These changes are said to be necessary to boost resilience amid disasters, even at the cost of efficiency.

We question these proposed remedies, though we are sympathetic to the motivations behind them; we also challenge the assumption that resilience can only be achieved if efficiency is reduced. Our overarching goal in this paper is to help readers develop a more nuanced and informed sense of why the current calls for dichotomy-based supply chain reforms (e.g., "Just-in-Time" to "Just-in-Case"; single- to dual-sourced; global to local sourcing) potentially set back the goal of building truly competitive supply chains that can also provide reliable and effective supply chain continuity despite the chaotic phenomena of a new and/or unanticipated disaster.

Our capability-based response argues that firms should work to develop the dynamic capability of changing flexibly and quickly between a competitiveness-first focus in "normal" times to a continuity-first focus amid a disaster. With strong pre-existing recovery and substitutive capabilities, a firm can potentially restore supply chain continuity without needing to increase the size of buffer inventory, move to dual sourcing, and/or make sudden moves to localize suppliers. Furthermore, with agile, adaptive protective capabilities, a firm can potentially respond to an unfolding disaster in real time to prevent the loss of supply chain continuity.

We start with a literature review that highlights the tradeoff between supply chain competitiveness and continuity. We then develop our argument through a formal model of this tradeoff when a disaster occurs, emphasizing the interplay of protection (provided by advance preparation as well as adaptation as the disaster unfolds), recovery time, and availability of substitution options. We then show the impact on these capabilities on moving the performance frontier ahead such that greater supply chain continuity **and** competitiveness are achieved.

Against this backdrop, we propose a Disaster Capabilities Map to show the conditions under which each type of capability should be applied and the interrelationships among them. To illustrate, we provide a fine-grained account about how one Japanese firm, Toyota, displayed an integrated disaster management approach in responding to the 2011 Tohoku earthquake, along with related examples of how Toyota has further boosted its disaster management capabilities in recent years. We also provide examples from other Japanese companies of actions taken during the COVID pandemic. We conclude by drawing upon our conceptual argument and empirical evidence to challenge typical Business Continuity Planning (BCP) approaches for being reactive, past-oriented, and disconnected from operational knowledge – and to speak directly against recent proposals to boost supply chain resilience through increasing inventory buffers, dual sourcing, and localizing of supply chains, all of which (in our view) can reduce competitiveness.

Literature Review

Although disaster mitigation (preparation) and responsiveness (recovery) in a supply chain are closely linked (Whitney et al., 2014), disaster management research in the literature has tended to focus on either mitigation (Hoffman et al. 2014, Knemeyer et al., 2009, Tomlin, 2006, Kleindorfer and Saad, 2005; Tang, 2006) or responsiveness (Chopra et al., 2007; Tomlin 2006, 2009; Chen et al., 2019). While early research on Business Continuity Planning (BCP) initially tended to fall into the latter category (Suresh et al., 2020), bridging these two categories is clearly a current focus of attention (Azadegan et al., 2019; Cook and Anderson, 2019; Benyoucef and Forzley, 2007).

Following this evolution in the literature, in this paper we treat preparing for a disaster and recovering from a disaster as an integrated set of activities. Through the right mix of organizational capabilities for mitigation and responsiveness companies seek to ensure continuity in the supply of goods (i.e., keeping the value stream flowing) in times of crisis, while maintaining competitiveness, or the right mix of quality, cost, and delivery, in normal times (Chopra and Sodhi, 2014).

Continuity of supply has generally been framed as a question of resiliency, with competitiveness generally framed as a question of efficiency. Companies need their supply chains to exhibit the right balance between resiliency and efficiency (Chopra and Sodhi, 2014; Czinkota et al., 2010). Increasing resiliency through redundancy (e.g., higher safety-stock levels, additional capacity, alternative sources) tends to be more costly in the short-run thereby reducing efficiency (Ivanov et al., 2019; Katsaliaki, 2021).

Resiliency can also be increased by creating information overlap through close collaboration between customers and suppliers (Fawcett et al., 2006, Goldsby and Stank, 2000), yet such practices also tend to increase costs, thereby reducing efficiency in the short-term (Nakano & Lau, 2020). The use of generic parts is also one way to increase resiliency (Sheffi, 2005); however, this reduces opportunities to work collaboratively with suppliers, thus potentially reducing long-term efficiency (Whitney, 1993; Fujimoto, 2001; MacDuffie, 2008).

Faced with a fundamental resiliency-efficiency tradeoff in supply chain management, research has shown that companies seek just enough resiliency to ensure continuity of supply in the event of severe disruptions (Pagell and Wu, 2009) and enough efficiency (coupled with effectiveness) to be competitive in an industry (Heikkilä, 2002; Park et al., 2018). Following these papers, we have reframed the supply-chain problem with respect to disaster disruption as a continuity-competitiveness tradeoff.

The Impact of Capabilities on Supply Chain Continuity and Competitiveness

In the value-flow-oriented approach to manufacturing (i.e., Lean/Toyota style production systems: Ohno, 1988, Monden, 1983, Womack et al. 1990, etc.), *supply chain competitiveness* and *supply chain continuity* are both defined as productive performance, or "goodness" of value from carrying design information to customers (Clark and Fujimoto 1991, Fujimoto 1999, 2001, 2012).

Here we model the competitiveness-continuity tradeoff, based on simple operations management formulas, and then show how it varies when supply chain continuity capabilities are weak(er) or strong(er). As our inspiration for this model derives from our empirical research on the recovery of Japanese manufacturers from the 2011 Tohuku earthquake and tsunami, we first summarize data from that period that provides certain parameters for our model; we then present the model; and we conclude this section with four prescriptions of the model for practitioners.

<u>Data</u>. In April 2011, Japan's METI issued an "Emergency Report of a Survey on the Industrial Situation after the Great East Japan Earthquake of 3/11/11". (Period of the survey: April 8~15, 2011; 80 firms were surveyed: 55 in manufacturing, 25 in service/retail). Of the 70 manufacturing firms that answered as of March 27, 2011, 64% (45) said their production sites had already recovered (about 2 weeks+); 75% (said they were/would be) recovered within 1 month; and

26% said their recovery would take 1~3 months. From these statistics, we may reasonably argue that the average recovery time at that time was roughly 2 weeks with standard deviation of 2 weeks.

In the same survey, about 70% of responding firms said they found substitution production sites for key inputs, and about 60% said their substitution production sites were located in Japan.

For inventory days, we draw on Financial Statement Statistics of Corporations by Japan's Ministry of Finance. In 2011, the year of the earthquake, inventory days (inventory value divided by cost-of-goods-sold) of the Japanese manufacturing industry was about 1.5 months, or 6 weeks; this level rose to about 7 weeks in the late 2010s.

The above data may indicate that, in 2011, most of the damaged manufacturing supply chains recovered from the damage of the earthquake within the firms' inventory days, so they continued to supply the end products despite the historic natural disaster.

<u>Integrated Approach to Supply Chain Competitiveness and Continuity</u>: Various disasters are certainly confronting us **some** day, but global competition confronts competing firms **every** day. Therefore, supply chains in competition-intensive industries should not take any anti-disaster measures that seriously sacrifice their competitiveness. In other words, they should choose *competitiveness-first* systems rather than *continuity-first* systems in normal times. If highly buffered "just-in-case" supply chains are less competitive, firms facing global competition should not choose them. Instead, what they should do during the period between disasters is, first, to adopt reasonable and functional "just-in-time" supply chains wherever they are more competitive; and second, to build certain dynamic capabilities for quickly switching their supply chains from the competitiveness-first mode to the continuity-first mode. As noted above, these include *protective, recovery*, and *substitutive* capabilities. In our framework and empirical examples, we identify how these capabilities are developed before, as well as during and after, a disaster occurs.

Recovery and Substitutive Capabilities: On the supply chain side, let's assume that the firms involved in this supply chain *j* are also producing similar products, and the latter's production processes may be used as alternative supply sources of commodity *i*. Then, when a disaster happens at the period *t* (DIS_t) and the supply chain *j* is damaged (DAM_{ijt}), the firms in the supply chain *j* have at least two alternative ways to restart production of *i*: (i) *recovery of the damaged production process*; (ii) *start of substitution production*. Let's call expected lead time for case (i) *recovery lead time* (RLT_{ijt}), and for case (ii) *substitution lead time* (SLT_{ijt}).

Thus, even when critical sites of supply chain *j* are damaged (DAM_{ijt}), (i) if *recovery lead time* (RLT_{ijt}) is shorter than inventory days *(IT_{jit}), or the amount of all inventories for supplying product i (I_{jit}), divided by daily (periodical) demand for i worldwide (D_{jit}):*

$$RLT_{ijt} \leqq IT_{jit} = I_{jit}/D_{jit}$$

then in-time recovery ($IREC_{ijt}$) is achieved, and *j*'s supply continues;

(ii) if *substitution lead time* is shorter than inventory days:

$$SLT_{ijt} \leqq IT_{jit} = I_{jit}/D_{jit}$$

then in-time substitution production ($ISUB_{ijt}$) is achieved, and *j*'s supply continues as well.

Let's call a set of manufacturing routines for shortening recovery lead time *recovery capability*, and those for reducing substitution lead times *substitutive capability*. Then the above inequalities indicate that supply chain *j*'s continuity is affected by the balances between product *i*'s inventories (I_{jit}) and *capabilities* of recovery and substitution production, given *i*'s periodical demand (D_{it}), as well as their uncertainties.

In the following analysis, we call the time for restarting the supply of the product *i* from the chain *j supply chain recovery lead time* ($SCRT_{ijt}$). When the recovery lead time of the damaged site is shorter than its substitution production lead time ($RLT_{ijt} \leqq SLT_{ijt}$), then recovery lead time of the damaged site *equals to supply chain recovery lead time*. ($SCRT_{ijt} = RLT_{ijt}$). Otherwise ($SLT_{ijt} \leqq RLT_{ijt}$), substitution production lead time becomes *supply chain recovery lead time* ($SCRT_{ijt} = SLT_{ijt}$). In other words,

$$SCRT_{ijt} = min.\ (SLT_{ijt}, RLT_{ijt})$$

Interactions between Capabilities and Inventory: It should be noted here that these firms' inventory level (I_{jit}) is also affected by their competitive capabilities (e.g., a set of manufacturing routines for Toyota/Lean Production System) that are accumulated continuously in the normal time (Ohno 1988, Monden 1983, Womack et al 1990, Fujimoto 1999). In other words, given the volume/timing of customer demand, a supply chain's manufacturing capabilities affect its inventory levels and competitiveness, whereas its recovery/substitutive capabilities affect its continuity, given the level of the inventory. There are dynamic and long-term interactions among demand, inventory, competitiveness, continuity, and capabilities for both competitiveness and continuity of a given supply chain, so they should not be treated separately.

Thus, our *capability-oriented approach* argues that a firm should build its capabilities and then prepare product inventories in accordance with such capabilities, rather than piling up inventories in fear of demand-supply uncertainties regardless of its capabilities. Note here that accumulation of inventories is rather easy, but accumulation of organizational capabilities is not (Nelson and Winter, 1982; Grant, 1996; Fujimoto, 1999).

Protective Capability: We have so far assumed that damage actually occurred in the supply chain when a disaster happened. However, when a certain disaster (DIS_t) happens, the sites in the chain *j* may still be able to avoid damage (DAM_{ijt}) by effective *protection* (PRO_{ijt}). The *damage occurrence ratio* (1- *damage protection ratio*), given the outbreak of a disaster, is as follows:

$$\textit{damage occurrence ratio} = Pr(DAM_{ijt} \mid DIS_t)$$

$$= 1 - (Pr\ (PRO_{ijt} \mid DIS_t)\ ) = 1 - \textit{damage prevention ratio}$$

For example, we may increase damage protection ratio by making the equipment and buildings robust enough to continue operation in the middle of a big earthquake. Likewise, the factory may successfully shut out infection by virus when the pandemic is going on outside. In any case, a set of organizational routines that can decrease a supply chain's *damage occurrence ratios* or increase its *damage protection ratios* may be called *protective capability*.

Supply Chain Continuation Ratio: Using this example, we can now define (i) *s*upply chain continuity ratio as conditional probability of either recovery or substitution, given a certain disaster. It should be noted that we can conceive of (i) *supply chain continuity ratio given the damage* (CONT-DAM_{ijt}), and (ii) *supply chain continuity ratio given the disaster* (event CONT-DIS_{ijt}).

$$\text{CONT-DAM}_{ijt} = \Pr(\text{IREC}_{ijt} \cup \text{ISUB}_{ijt} \mid \text{DAM}_{ijt})$$

$$= \Pr(RLT_{ijt} \leqq IT_{jit} \cup SLT_{ijt} \leqq IT_{jit} \mid \text{DAM}_{ijt})$$

$$\text{CONT-DIS}_{ijt} = \{1 - \Pr(\text{DAM}_{ijt} \mid \text{DIS}_t)\} + \Pr(\text{IREC}_{ijt} \cup \text{ISUB}_{ijt} \mid \text{DIS}_t)$$

$$= \Pr(\text{PRO}_{ijt} \mid \text{DIS}_t) + \text{CONT-DAM}_{ijt} \cdot \Pr(\text{DAM}_{ijt} \mid \text{DIS}_t)$$

$$= \Pr(\text{PRO}_{ijt} \mid \text{DIS}_t) + \Pr(\text{IREC}_{ijt} \cup \text{ISUB}_{ijt} \mid \text{DAM}_{ijt}) \cdot \Pr(\text{DAM}_{ijt} \mid \text{DIS}_t)$$

For the latter indicator (CONT-DIS_{ijt}), note that the supply chain continues if damage-protection is successful in the first place (the first term), or if in-time recovery or substitution is successful (the second term), given the occurrence of the disaster.

It follows from the above operational definition that supply chain continuity at the time of disaster (DIS_t) requires at least three types of organizational capabilities: (1) *recovery capability* for in-time recovery of the damaged spot (IREC_{ijt}); (2) *substitutive capability* for in-time start of substitution production ($ISUB_{ijt}$); (3) *protective capability* for reducing supply chain damages (PRO_{ijt} or 1- DAM_{ijt}), given the level of inventory (I_{jit}) and demand (D_{jit}).

Competitiveness-Continuity Frontier: As noted, we treat supply chain competitiveness and supply chain continuity as integrated rather than separate._Certainly, there is a tradeoff (negative relationship) between supply chain competitiveness and supply chain continuity, given the firm's capabilities. But if capability building takes place, on both competitiveness and continuity dimensions, this frontier may shift outward, with higher competitiveness and continuity at the same time, given volume, timing and uncertainty of customer demands.

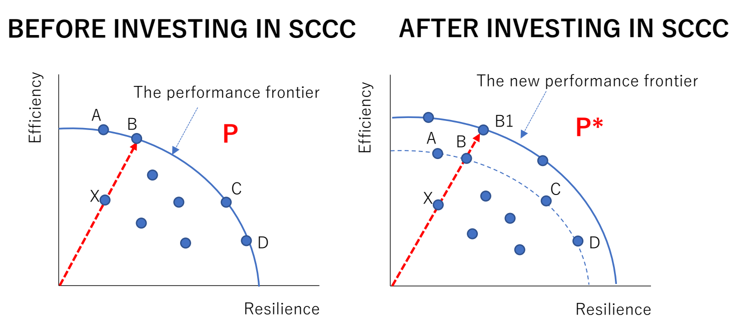

Figure 1: Investing in supply chain continuity capabilities (SCCC) shifts the performance frontier

Figure 1 about here

Shifts in the performance frontier of this sort are typically modeled as a set of concave curves with firms whose capabilities are improved able to move to the furthest-out curve (Figure 1). However, we propose a different way to show how the competitiveness-continuity frontier expands as we build recovery, substitutive, and protective capabilities in the context of industrial disaster management, particularly in the era of COVID.

We start with two reversed probit curves (assuming normal distributions of the same shape for simplicity), one for competitiveness (in-time delivery achievement ratio) and one for continuity (in-time supply chain inventory recovery ratio).

First, if a firm's inventory days (e.g., 6 weeks, see above) reflect its actual delivery lead times, and presuming that customers' demands for delivery lead times have a relatively fixed distribution, in-time delivery ratios (an indicator of competitiveness in delivery) drop as the actual delivery lead times get longer. Note here that inventory days are directly associated with delivery lead times when the firm adopts a complete make-to-order system, as opposed to a make-to-stock system, with the first-in-first-out (FIFO) inventory rule, just like a complete conveyer line from arrival of materials to shipment of goods. This may seem to be a strong assumption, but at the level of whole industries, we can say that a majority of the production sites, including those for intermediate goods, carry out make-to-order production.

For simplicity, we also assume that customer demands for lead times are normally distributed with a certain average (at the inflection point; e.g., 6 weeks, see above) with a standard deviation of 1 week. Then, when we can reasonably assume that inventory days reflect actual delivery lead times, the competitiveness curve, measured by in-time delivery ratios given the inventory days (actual lead time) follows a reversed probit curve (cumulative normal distribution function) as in Figure 2.

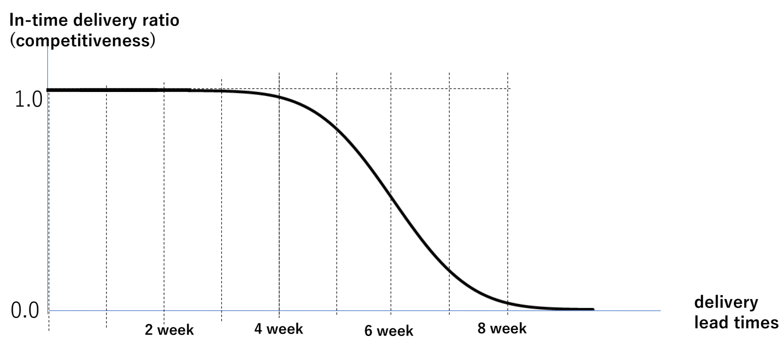

Figure 2: Tradeoff between delivery ratio (competitiveness) and delivery lead times

Figure 2 about here

We further assume that a firm that aims at about 98% in-time delivery ratio may set its actual delivery lead time at 2σ (e.g., 2 weeks) earlier than the average of the demanded lead times, or 4 weeks in the above figure.

On the other hand, *supply chain recovery lead times* -- or *min(damaged spot recovery lead time, substitution production lead time)* -- get shorter when recovery or substitutive capabilities are built properly in advance during the normal time.

Here, capability of substitution production/supply is very important as the substitution lead times are less uncertain than damaged spot recovery lead times, as the latter is highly affected by all kinds of uncertainties under the disaster. Then we may say that the minimum of damaged spot recovery lead time and substitution production/supply is *supply chain recovery lead time*. Because the firm affected by the damages by a disaster faces significant uncertainties, we argue that the predicted supply chain recovery times are distributed in a certain way (e.g., normal distribution).

Now, for simplicity, let's assume that the supply chain continuation curves, given the recovery/substitutive capability, follows a probit curve of the same standard deviation (e.g., 1 week) with the lead times normally distributed, given the inventory days. When capabilities are weaker, the curve looks like the left side of Figure 3. If a firm sets its inventory days (actual delivery lead time) at the level of 4 weeks, as in the above case, the probability of its supply chain continuation is as low as 2%. But as shown on the right side of Figure 3, when the recovery/substitutive capabilities of the firm get stronger, the curve shifts to the left (e.g., by 3σ). When the firm keeps its actual delivery lead time (inventory days) as 4 weeks, now it can achieve much higher probability of supply chain continuation (e.g., 80%).

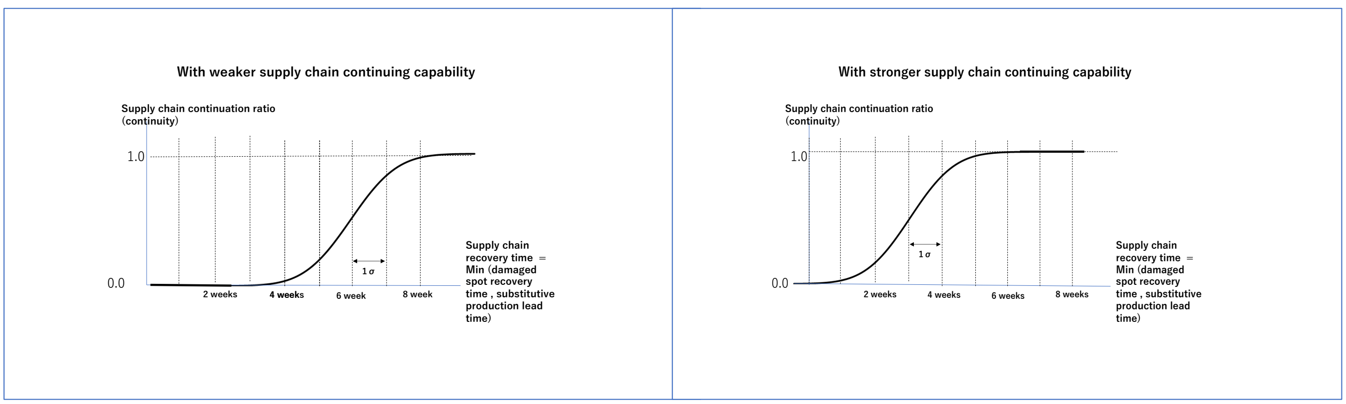

Figure 3: Tradeoff between supply chain continuation ratio (competitiveness) and supply chain recovery time – with weaker and stronger capabilities

Figure 3 about here

When the competitiveness (in-time delivery ratio) curve and the supply chain continuation curve are overlapped, we have the following two patterns of continuity and competitiveness curves combined, as shown in Figure 4, again contrasting weaker and stronger capabilities.

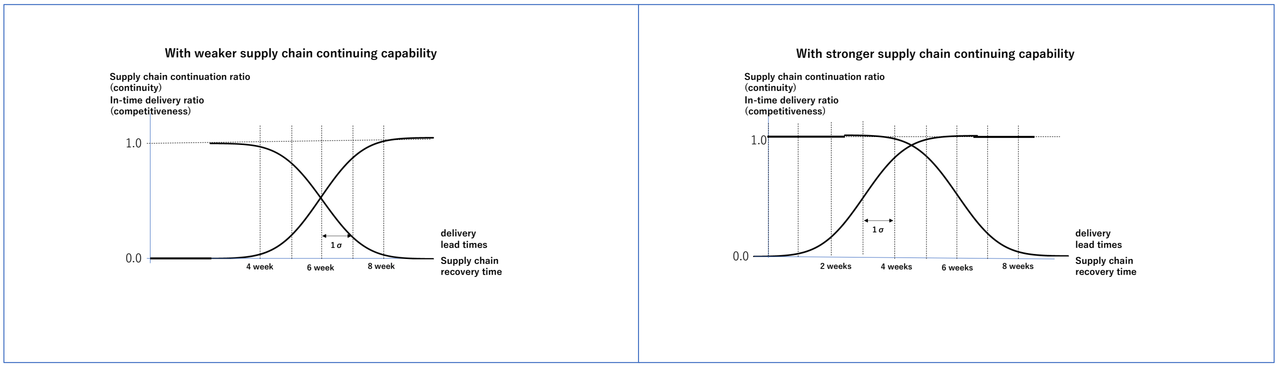

Figure 4: Tradeoff between delivery ratio and delivery lead times mapped onto
tradeoff between supply chain continuation ratio and
supply chain recovery time – with weaker and stronger capabilities

Figure 4 about here

Now we connect the above analyses of competitiveness and continuity into an integrated frontier analysis by erasing the time factors. In Figures 5 and 6, we find, graphically, interesting patterns of the contraction and expansion of the frontiers as the firm's recovery/substitutive capabilities are reduced or enhanced, given the competitiveness curve already built in normal times. Figure 5 shows the frontiers from weak to extremely weak capabilities and Figure 6 shows the frontiers from strong to extremely strong capabilities. Note that we normalized the lower and upper bound of both continuity and competitiveness variables as (0,1). Note also that, as the firm's actual lead times (measured by inventory days) get shorter, the points in the above frontiers move from the upper left point (0, 1) to the lower right point (1, 0).

For simplicity, the continuity curves are reversed probits of identical standard deviation, but the basic patterns will not change much even if we relax this assumption. The difference between these frontiers depends upon the distance between the two inflection points, in σ's.

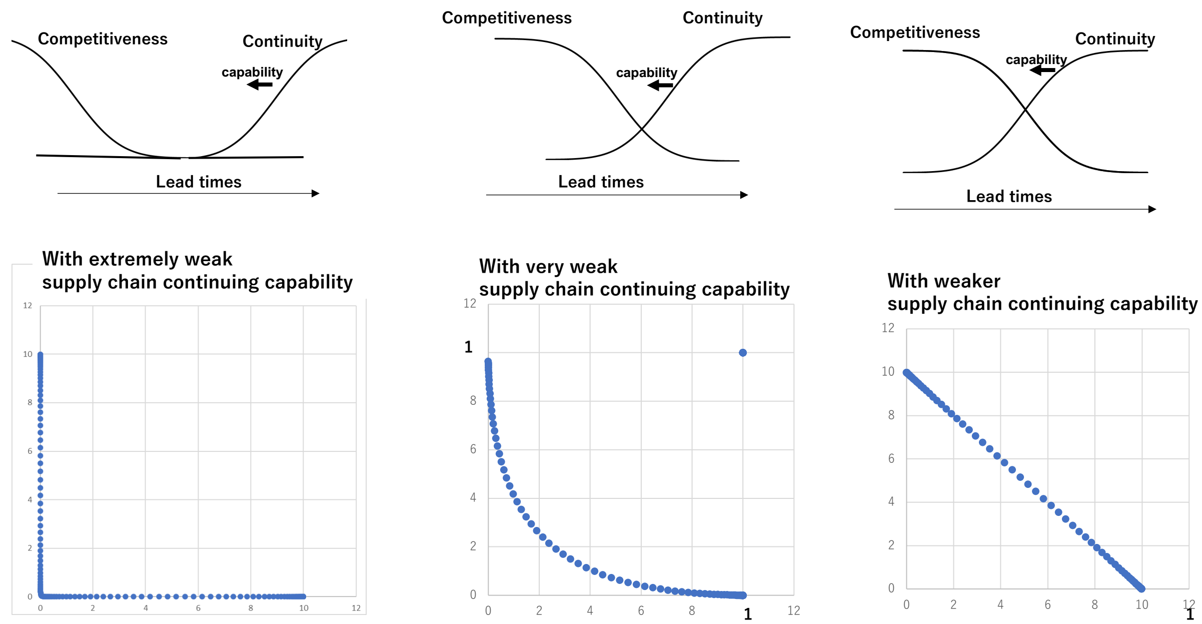

Figure 5: How weak(er) capabilities affect competitiveness-continuity performance frontiers

Figure 5 about here

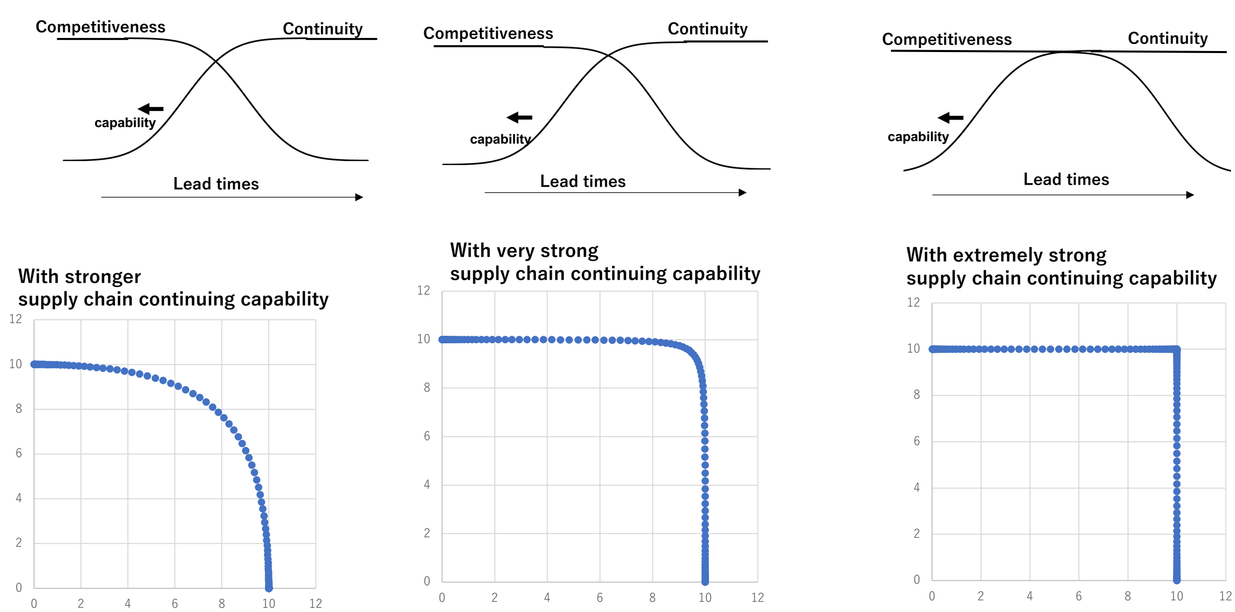

Figure 6: How strong(er) capabilities affect competitiveness-continuity performance frontiers

Figure 6 about here

When the recovery/substitutive capabilities are weak (the three cases in Figure 5), given any kind of downward-sloping indifference curves between continuity and competitiveness, the choice will tend to be either of the two endpoints of the frontier, suggesting unstable decisions of either-or dichotomy between competitiveness and continuity. When the capabilities for supply chain continuity are built up to be stronger (the three cases in Figure 6), by contrast, we are likely to choose more balanced positions, which approach to the best (1,1) point as the firms keep on building up their anti-disaster capabilities in normal time.

Prescription. The above analysis, based on our capability approach, suggests the following four prescriptions for practitioners:

1. Given the distribution of the customers' demanded delivery lead times, choose the target delivery lead times (and corresponding inventory days) in terms of in-time delivery ratios.
2. Build competitive capabilities for achieving the abovementioned target lead times.
3. If the abovementioned delivery lead times (inventory days) are too short for achieving sufficiently high probability of supply chain continuation, build recovery/substitutive capabilities so that the recovery/substitution lead times get shorter on average.
4. If the customers become more demanding on delivery lead times, continue the above cycles of the dual capability-building for rebalancing the competitive and anti-disaster capabilities.

Note that the above approach is significantly different from the buffer approach that tends to deal with supply chain competitiveness and continuity separately. In other words, our capability approach is more integrated in that we focus on the balance between supply chain competitiveness in normal times and supply chain continuity in time of emergency. Besides, when a major disaster happens, the firms should also use its protective capabilities to minimize the probability of damages of its sites, or Pr (damage|disaster) in the first place.

Having established these general propositions about how capability-building (*protective, recovery, and substitutive*) can shift the performance frontier, creating a new, higher performance tradeoff point between supply chain competitiveness and continuity amid a disaster, we now consider how these specific capabilities interrelate.

How the Supply Chain Continuity Capabilities Interrelate

To illustrate how these three capabilities relate to each other – and how we apply them in cases of disaster management, let us address one of the most central supply chain management issues – how much inventory to hold. There is now considerable debate about the appropriate way to manage amid a pandemic, with many arguing that "just-in-time" production and lean manufacturing optimize efficiency but with insufficient inventory buffers.

For instance, we know that even just-in-time (lean) supply chains may keep two weeks of product inventory somewhere in the pipeline for a typical item.[4] Inventory levels are set in relation to demand. The inventory stock equals the amount of demand per day, multiplied by the number of days judged appropriate for competitiveness-first operations. The firm also needs to know the time to ramp up substitution sources of production in relation to days needed to reach the calculated inventory stock. Knowing these three variables (demand per day, policy on how much inventory to hold in normal times, ramp-up time for recovery and/or substitution), the firm can make effective decisions for responding to any given disaster.

More specifically, consider the following set of calculations:

[4] Note that Toyota's average parts inventory in normal time is roughly 1 to 2 weeks, even in Japan where suppliers are close to Toyota's factories. This differs from the popular perception that Toyota's inventory levels are near zero. We do not propose "zero inventory" as effective practice; even lean production needs certain levels of inventories for product cycles, supply pipeline, seasonal variation and de-coupling from too-tight interdependence (Chase & Aquilano, 1991).

Inventory Stock = Demand per day (market) x # of days (policy for normal-times competitiveness)

If a particular product has X weeks of product inventory, then the target recovery lead time for this item for continuing the supply chain is also X weeks. If the estimated recovery period is shorter than the inventory period, then the firm may concentrate its efforts on recovery on-the-spot.

(1) If *Recovery time (days) * Lost Production (units/day) < Inventory Stock*,
apply Recovery capabilities;

(2) If *Recovery time (days) * Lost Production (units/day) > Inventory Stock*,
and *Substitution Ramp Up Time < Recovery Time,*
apply Substitutive capability;

(3) If *Recovery time (days) * Lost Production (units/day) > Inventory Stock*,
and *Substitution Ramp Up Time > Recovery Time,*
persist with Recovery capabilities.

If the estimated recovery period is shorter than the inventory period (1), then the firm may concentrate its efforts on recovery on-the-spot, but substitution production should stand by as a back-up, as anything can happen during emergencies. If the recovery period is longer than inventory time and the substitute production station ramp-up time is predicted to be shorter than recovery time (2), then the firm may choose substitution production at least temporarily before the on-the-spot recovery is complete (Fujimoto & Park 2014, Fujimoto & Heller 2018). The focus could also be entirely on recovery time if it is considerably shorter than substitution ramp-up time.

Under conditions (2) and (3), firms will face an interruption in their production and a loss of supply chain continuity due to a disaster. Increasing inventory stock is one way to respond. In this regard, we agree that there is a tradeoff between inventory stock levels and the ability to maintain supply chain continuity in the face of various disasters. However, the investment in capabilities can change the situation considerably. This investment can shift the production function frontier outwards, allowing a path to supply chain continuity that doesn't involve boosting inventory.

To illustrate how these capabilities function together to help a firm deal with disasters of all types, we summarize the above material in a single framework, a Disaster Capabilities Map.

Framework: Disaster Capabilities Map

Table 1: Disaster Capabilities Map

Capability	Protective	Recovery	Substitutive
	5S and sanitizing protocols for normal operations *(before disaster)*	Daily kaizen and flow management *(before disaster)*	Preparing real and/or virtual dual lines *(before disaster)*
Planning (e.g. BCP) and capability-building	*Building robust factories & facilities in the first place*	*Special rescue team w/ general purpose recovery tools /skills*	*BCP via building real dual production lines; and/or virtual dual tests*
	***	***	***
	Mobilizing measures to protect facility/supply route *(during disaster)*	Fixing the disrupted facility/supply route *(after disaster)*	Temporary dual sourcing *(after disaster)*
Actions as planned and emergent actions guided by capabilities	*Keeping factories running (e.g. none/few infections)*	*Quick recovery of damaged/infected factories*	*Quick ramp-up of substitutive production whenever necessary*
	Toyota	Toyota	Toyota
	Panasonic	Isuzu	Funabashi

Table 1 about here

The Disaster Capabilities Map (see Table 1) has three columns, for Protective, Recovery, and Substitutive Capabilities; within each, we explain how the capability is developed and applied before, during, or after the disaster. Next we describe each capability in more detail, and subsequently we describe the examples (Toyota across all 3 capabilities longitudinally; Panasonic, Isuzu, and Funabashi for recent during-COVID actions).

Protective Capability

Protective capability is the ability of firms to minimize the damage inside facilities, sites, and routes of the supply chains in question *during* the disaster (e.g., *after* the disaster has happened outside but *before* its negative effects occur inside the factory). Protective capability is particularly important when there is a time-lag between a disaster's occurrence outside and its negative impact inside, during which firms and sites may be able to do various preventive activities. COVID-19 may be one such case, in which inter-firm differences in protective capability accumulated in normal times may matter greatly at a time of emergency. Thus, protective capability aims to minimize the damage inside the site, given the occurrence of the disaster outside it.

This is not always possible, as when a powerful physical disaster instantly destroys the community and the firm's facilities at the same time (e.g., big earthquakes, tornadoes, explosions), or when the invasion of the disaster is difficult to stop (e.g., radioactive contamination by explosions at a nuclear power plant). We may still make the buildings and machines strong, fix the machine tightly on the floor or elevated above the emergency water levels, build high walls against tsunami, and so on, as another type of preparation, but history shows that truly devastating disasters often overwhelm such plans.

Recovery Capability

Recovery capability is the capability of executing recoveries of damaged facilities and routes on-the-spot quickly and safely *after* the damage caused by the disaster. This capability includes immediate dispatching of advance diagnosis teams; quick and accurate diagnoses of the damage; on the spot estimation of required time, resources, and skills for the recovery; quick and safe dispatching of the recovery assistance teams with sufficient equipment; and execution of previously-planned recovery activities, including quick revision of the plans and actions as unanticipated events occur one after another on the spot. Recovery-capability building in normal time is also crucial, and asset-specific knowledge and process-specific capability are important in addition to company-wide BCP. Thus, recovery capability aims to minimize the resources necessary for getting the damaged sites and routes back to reasonably normal.

Substitutive Capability

Substitutive capability is a complementary capability of the aforementioned recovery capability in that its execution works *after* the disaster has caused damage inside facilities and to supply routes. Substitutive capability complements on-the-spot recovery efforts particularly when the recovery is predicted to be seriously long (e.g., when the facility in question is totally destroyed by fires, explosions, tsunami, etc.; when the factory floor is under water due to major and prolonged flooding; and when the process is highly complex and needs a long time for precise adjustments). In such cases, quick and accurate ramp-up of substitution production of the affected item at other factories is critical.

As in the case of recovery capability, continuous capability building for substitution production in normal time is crucial. In addition, asset-specific knowledge is key for quickly and accurately transferring product-specific design information (e.g., drawings, NC programs, dies, tools, skilled engineers/operators, recipes) from the affected production processes to unaffected ones to make the latter a “virtual dual” line whenever necessary (Fujimoto & Park 2014, Fujimoto & Heller 2018). A “virtual dual” line is pre-tested to make sure that when the digital designs/recipes/programs from the original factory are transferred and implemented at the second site, production will be successfully attained – but this capability is not “turned on” until absolutely needed. Nor is the production line at the second site "mothballed" in readiness for a transfer; it continues to make its regular products.

Research Methods

We focus, in our case examples, on what we know best -- the supply chains supporting global capital-intensive manufacturing industries such as automotive. In giving examples of supply chain capabilities, we draw on specific, often outlier, cases to illustrate our point rather than a methodology that seeks to identify central tendency and variations around that mean.

The Toyota case in this paper draws from our extensive fieldwork at the automaker dating back to the 1980s (e.g., Clark and Fujimoto, 1991; Fujimoto, 1999; MacDuffie and Helper, 1997). A visit specifically about disaster risk management was made by the second and third authors to Toyota on October 28, 2016 where we conducted a two-hour interview with two high-ranking managers and one senior executive at the company, all of whom had deep knowledge and experience on the subject. Later the same day we conducted a three-hour interview with a former Toyota manager, who had over twenty-years of hands-on experience directing disaster recoveries at suppliers in Japan since 1991.

Fujimoto et al. (2018a) describes the evolution of Toyota's capabilities for preventing and recovering supply chain disruptions due to natural and man-made disasters. Fujimoto et al. (2018b) describes Toyota's long-term learning from its disaster recovery experiences, as related by Hiroaki Koda, who led Toyota's contribution to the government-supported inter-industry recovery project of a major semiconductor plant that was severely by the 2011 earthquake and tsunami.

We supplemented primary data collection at Toyota with extensive first-hand data collected during a research project on two major supply-chain disruptions and recoveries in Japan, one in 1997 and the other in 2007, that were closely supported by Toyota. Details about this project and its main findings can be found in Whitney et al. (2014) and Heller (2018).

We collected case information on the COVID-19 experiences of Panasonic and Isuzu through direct electronic correspondence with the companies in 2020. The Isuzu factory described in the case has been visited by all three authors, with the second author having visited it more than ten times over the past 30 years. The second author has also visited the Panasonic factory described in the case multiple times. Data on Funabashi has been obtained from second-hand sources.

Toyota

Here we provide an extended examination of Toyota because it provides examples across more of our Disaster Capabilities Map than any other company we've studied. We have documented the evolution of Toyota's disaster capabilities over the past forty years (Fujimoto et al., 2018a) and found the consistently strong belief at the company that its daily competitiveness does not stand in opposition to its disaster readiness. Rather, Toyota considers the individual skills and organizational processes that the company is continually seeking to improve as having consistently proven to be highly effective when responding to a disaster. As such, the first step in disaster preparedness at Toyota is considered to be a commitment to the two pillars of the Toyota Production System: Built-in quality and Just-In-Time production (Ohno, 1988). The second step is creating a system that connects front-line experience with disaster risk assessment and mitigation efforts.

During a major disaster, Toyota's capabilities are deployed by a "war room" set up by an advance team at a disrupted site. The advance team is comprised of people who are highly experienced in solving production problems on a daily basis within and between plants – of both Toyota and its suppliers[5] – as well as purchasing, telecommunications, and plant engineering

[5] See MacDuffie & Helper (1997), Helper, MacDuffie, & Sabel (2000), and MacDuffie & Helper (2006) on how OEMs can work effectively with suppliers on mutually advantageous goals of innovation, quality improvement, cost reduction, and smooth and speedy product changeovers – and how a lack of interorganizational trust between such firms can impede achievement of those goals even when individual employees of the respective firms have a high level of interpersonal trust. Achieving trust within the supply chain is thus another capability that underpins effective disaster recovery – one that must be developed continuously, i.e., before, during, and after disasters.

personnel. Using their trove of knowledge, the advance team quickly analyzes the problems caused by the disaster. They then pull in whatever support is needed from the rest of Toyota by closely coordinating with a Disaster Response Center that is established within Toyota's production control department whenever a major disaster strikes. Over time the interval between the arrival of the advance team and the arrival of the main recovery team has shrunk, as Toyota's understanding has deepened about what will be needed when and who in Toyota can provide this expertise.

The lead for disaster-related capability development at Toyota is the Operations Management Development Department (*Seisan Chosa Bu*), which is mainly charged with supporting *kaizen* or continuous improvement activities at Toyota, its suppliers, and its logistics partners. OMDD members also form the core of the advance team that goes to a disrupted site. A former head of OMDD and a senior advisor to the company, Nampachi Hayashi, one of the last direct proteges of Taiichi Ohno, has played a leading role in deciding how Toyota has dealt with disasters over the years.

Lessons learned from serious disasters are discussed and incorporated into Business Continuity Plans (BCP) at Toyota. However, Toyota understands that in order for such plans to work, there must be people on the ground who can make quick and accurate judgements and take decisive action in a crisis situation. We were repeatedly told that daily problem solving at production sites is the best way to train such people. At the same time, experienced staff who can make sound decisions are also needed at the centrally located Recovery Support Center.

We were told that one early trigger for increased systematic awareness of the need to develop disaster recovery capabilities at Toyota was the 1959 Isewan Typhoon that caused large-scale flooding in the Tokai area of Japan, where many of Toyota's auto plants and suppliers are located. From this experience, Toyota learned that in order to build goodwill in a crisis, it is critical to prioritize the recovery of the production lines at a supplier that are used for making parts that will be delivered to *other companies*, not Toyota. Any production lines at a disrupted supplier that are dedicated to supplying Toyota parts must be the last ones to be recovered.

Another early trigger for companywide disaster capability building at Toyota was a major fire in 1979 inside of an expressway tunnel through a mountainous region of central Japan. Deliveries from 65 suppliers were disrupted and two of Toyota's auto plants had to shut down for lack of parts. Toyota's disaster capabilities passed a hard test in 1995 when the company helped quickly recover some important suppliers that had been severely disrupted by the Kobe earthquake. By this time, the core values of Toyota's disaster recovery efforts were firmly set in place, the most important of which is agreement by everyone involved that the company's contributions to saving human lives and supporting rescue efforts for the surrounding community must never take a back seat to production recovery.

Another key principle is that Toyota must first seek to recover the site that was disrupted. Only in cases where the time to recovery is judged to be too long should substitution production be considered. Involving other companies in substitution production should only be done on a temporary basis and should only be considered when the disrupted company's own sites are unable to do the job.[6] In this way, trust between suppliers and Toyota can be maintained, since a disrupted supplier does not have to fear that its business will be taken away from it due to a disaster.

Two examples noted earlier are worth recalling here. In 1997, a fire destroyed all the production lines used to machine a brake part at an Aisin Seiki plant that supplied 90% of Toyota's volume for this part. Many observers said that this showed Toyota's Achilles' heel. However, substitution production sites were up and running within three days. Toyota's plants returned to pre-

[6] Note that Toyota's prioritization of recovery over substitution is different from our model's prescription that substitution should be chosen before recovery because the former is less uncertain, amid disaster, than the former.

disaster production volume within nine days, with sixty-two suppliers ultimately performing substitution manufacturing of the part (Nishiguchi and Beaudet, 1998).

Ten years later, the 2007 earthquake on the West coast of Japan disrupted all the automotive piston ring production lines of Riken, which supplied half of all such rings manufactured in Japan. Within days assembly lines of automakers throughout Japan had to stop production. However, a massive recovery effort led by Toyota restored production on most lines at Riken within one week.

The scale of disruption caused by the massive earthquake and tsunami that hit northeastern Japan in 2011 overwhelmed Toyota's disaster capability. Even so, most of the 600 disrupted sites in Toyota's supply chain were back online within two weeks. In contrast, it took Toyota more than one month to identify exactly how many suppliers' sites were damaged by this disaster when we include all of Toyota's domestic multi-layer supply chain consisting of over 10,000 firms and sites.

Following this very difficult experience and in order to speed up responses to future disasters, Toyota leveraged its trust-based relationship with its suppliers to create a comprehensive cloud-based proprietary database (REinforced Supply Chain Under Emergency) that reached down to the lowest tiers of its supply chain in Japan. RESCUE contains up-to-date information on thousands of suppliers and is linked to a governmental hazard map for earthquakes, tsunami, and floods. RESCUE was co-developed with Fujitsu, which sells a commercial version of it. Thus, Toyota once again demonstrated its evolutionary capability, or dynamic capability-building capability of handling unexpected and emergent processes (Fujimoto 1999).

Toyota also created an access portal that allows real-time rerouting information to be delivered to logistics companies and drivers in a disrupted area. A lesson Toyota learned after the Kumamoto earthquake, in 2016, was the need for the company itself to monitor inventory levels throughout its supplier network. In the past, each tier had been responsible for monitoring the inventory levels of the tier below it, but now Toyota keeps track of this information too.

Responding to COVID-Related Situations: Examples from Japanese Firms

In our examination of physical disasters, we have found that in nearly every case it was either a near miss or severe damage from a disaster that drove a company to take its disaster capability building to the next level. Since COVID-19 is affecting companies around the world, we expect that this pandemic will be the trigger that causes many more companies around the world to start taking disaster capability preparation and execution seriously. Three examples from Japan -- Panasonic, Isuzu, and Funabashi -- demonstrate capability-based responses to the COVID-19 disaster observed over the spring and summer of 2020.

Protective and Substitutive Capability: Panasonic, During COVID

Panasonic's Kofu factory in Japan shows both preparation and execution of protective capability and substitutive capability. The Kofu factory develops and produces semiconductor manufacturing equipment (e.g., surface mounter technology) as part of one of the firm's divisions (Connected Solutions Company). The plant experienced a sudden supply shock due to COVID-19. In January 2020, Panasonic's Chinese parts suppliers, and then in March, those in countries A and B in ASEAN, could no longer supply parts to due to national lockdowns.

However, Panasonic was able to switch its supply sources temporarily from China and country A to Japan rather smoothly, because the firm, using lessons learned from the 2011 Tohoku earthquake, had included in its purchasing contracts possible substitution production for core custom-designed parts. Standard parts from country B were substituted with similar parts available in the market. When design changes were made, Panasonic's engineers quickly judged if substitute parts were functionally equivalent. If durability of a part went down, the firms' after-service unit guaranteed customers that it will make up for it with strengthened maintenance support. Unexpected supply chains changes were dealt with by a cross functional emergency team (including engineering/purchasing/production units) operating around-the-clock including through holidays.

On the demand side, at the beginning of 2020 business projections were very difficult due to various mixed effects, including COVID-19. However, some Asian ODM firms, backed by increasing demand for products related to digital transformations (e.g., 5G networks), started to suggest, as early as February, the possibility of large orders coming for semiconductor equipment. Anticipating this wave of the orders, the Kofu factory decided to take the risk and launch a full production plan starting from April, despite the Japanese government's declaration of a state of emergency[7] around that time. The factory's thorough commitment to anti-virus measures persuaded its main suppliers to go along with this plan. Some parts factories in Japan did shut down due to COVID-19 infections, but Panasonic made use of the multi-tier supply chain information system it had created after the 2011 Tohoku earthquake (much like Toyota) and managed to maintain its supply chain through substitution production, including using its own factories.

Panasonic's commitment to continued production and reliable delivery made it possible for the Kofu factory to accept the large orders that started to come in from ODMs and full production began in April 2020. Panasonic has demonstrated its protective capability by keeping in-factory infections at zero. Twenty anti-COVID-19 measures[8] can be identified at the Kofu factory, about half of which were newly introduced mainly around March-April 2020. The ones that already

[7] The Japanese government declared a state of emergency in April/May, but there were no major lockdowns, so most factories in Japan continued to operate throughout 2020 and 2021.

[8] Anti-COVID-19 measures at the Kofu factory include: strong alkaline water used for washing parts; thorough disinfection of every room and corner of the factory buildings; set up of many in-building gates for checking body temperature and sanitation; changed production process layout for keeping distance between operators; maximizing ventilation, stopping face-to-face discussions and eliminating sharing tableware in the dining halls; and heavy use of remote communication tools for collaboration. The Kofu factory was helped by the fact that most of its employees commute by privately owned cars, which is a safer means of mobility during a pandemic.

existed before the pandemic were strengthened around this time. The psychological aspects of anti-virus protection, such as alleviating uneasiness on the side of employees, suppliers, and the surrounding communities, have been managed by increased communication and information sharing. Panasonic told us that employees at the Kofu factory say they are confident that it is safer inside the factory than outside, but every morning employees still exchange the new greeting, "Are you doing OK against COVID?"

Protective and Recovery Capability: Isuzu During COVID

With the outbreak of the pandemic in early 2020, Isuzu like other leading Japanese firms deployed its operational capabilities to protect its plants from infections, including introducing screening for employees upon entering a plant and implementing various social distancing measures. On April 6, one person who worked at Isuzu's factory (its largest in Japan, located right next to Tokyo, employing 6000 people who mostly commute by public transportation) was diagnosed with COVID-19. Shortly thereafter two more people who worked at the plant received the same diagnosis, one on April 9 and the other on April 10.

While all three workers worked at different locations inside the plant and 56 employees who had had close contact with them had gone into home isolation, Isuzu decided to shut down the plant for five days starting April 13 to reduce the possibility of any further infections. The company president, Masanori Katayama, realized this decision would be hard on the plant's many Just-In-Time suppliers, but he decided that his first priority was to protect the surrounding community. After the plant re-opened with redoubled efforts to prevent infections, there were no further cases of infection in the plant, although one person who worked in the R&D facility was diagnosed with COVID-19 in July.

Although we place this example in a single cell (*recovery preparation*), it can also be viewed as spanning two other cells in our capability map. The precautions taken to prevent infections fit into *protective preparation* and closing and disinfecting the plant fit into *recovery execution*. Overall, this example shows an overall disaster management approach under which the company prepared the plant for quick recovery by its prevention measures (consistent with its long-standing emphasis on operational excellence[9]) and executed the rapid voluntary closure of the plant due to its overarching commitment to the wellbeing of the surrounding community.

Substitutive Capability: Funabashi During COVID

Toyota (2020a, 2020b) reports how, amid the pandemic rush in the spring of 2020, the company sent production personnel to support large productivity and volume increases in the emergency manufacturing of disposable protective medical gowns made by Funabashi, a small manufacturer of rainwear with less than 40 employees in Nagoya that was founded in 1921.

Early in April 2020, Funabashi received an urgent call from the Japanese Ministry of Economy, Trade, and Industry inquiring if it could try producing medical gowns, as the nation faced a projected major shortage of personal protective equipment (PPE). Working with a nearby hospital the company made a prototype, and its efforts to ramp up production to 10,000 medical gowns per month was reported in an article in Asahi Newspaper on April 21. Toyota approached Funabashi after the article was published with an offer to help increase production.

Within two days after first contact, Toyota sent a team of eight experienced personnel to support production process kaizen at Funabashi's plant, which consisted of making modifications of standard operating procedures, overhauling the existing production equipment including adding hand-made upgrades using household items, making changes in production layout, and establishing a production control system for monitoring production volumes at each of the four steps in the production process. Very little new equipment was added.

[9] See Sasaki & Itohisa (2010) for a case study of Isuzu and discussion on how measures of organizational capability tied to operational excellence are related to profitability.

Funabashi found six companies from different industries, all of which had no prior experience supplying medical gowns, who joined together to meet a rush purchase request from the Japanese government for 400,000 gowns per month. By mid-May, the alliance of companies had surpassed this production target by 25%. Toyota leveraged its accumulated experience in transferring knowhow across its plants to help Funabashi quickly transfer skills and knowledge for making the medical wear to the other companies in the alliance. Furthermore, during this transfer, companies were able to learn from each other and incorporate numerous production improvements.

Discussion

We have presented our model of the continuity-competitiveness tradeoff and the impact of investing in capabilities; explained our framework for analysis, the Disaster Capabilities Map; and supported it with evidence from both the longitudinal Toyota case and three COVID-specific examples. We now summarize our overall assessment by expressing our opposition to three popular ideas receiving heightened attention in the midst of the pandemic: 1) Just-in-case buffers and dual sourcing; 2) Unilateral localization; and 3) Increased business continuity planning (BCP).

1. Just-in-Time vs. Just-in-Case Buffers (and Single vs. Dual-Sourcing)

Policy on inventory stock as well as recovery time and substitution ramp-up time are clearly endogenous and related to capabilities. Advance preparation of capabilities for recovery and/or substitution production can shift the efficient frontier so that inventories don't need to increase to maintain supply chain continuity. Those capabilities can also be utilized when a single source supplier is quickly depleted or taken out of action by a disaster, helping that supplier recover (perhaps with the help of temporary substitution production) rather than switching to dual sources.

Taking two weeks as the standard inventory level in normal times, this approach means that if the disaster-damaged production/logistics facilities can be recovered or switched to temporary substitution production within two weeks, then such supply chains can continue to function. In fact, this is what was observed in many production sites and products after the 2011 Tohoku earthquake. Except some extreme cases (e.g., factories near the Fukushima #2 nuclear plants or those totally washed away by the tsunami), many Japanese supply chains, after the fact, demonstrated their supply-chain-continuation capabilities, prepared in advance or emergent, within a time period of two or three weeks. Furthermore, when facilities have strengthened their disaster-protective capability beforehand, the number of seriously damaged sites may be minimized in the first place, so that firms, sites, and communities can concentrate their limited resources where the damage is greatest, speeding up their recoveries.

Thus, our argument is that, instead of adding buffers permanently to reach, say, a 3-month level of inventory in anticipation of the next major disaster, firms should keep a reasonably lean supply chain with, say, 2-3 weeks' product inventories in normal time, while building capabilities for recovery/ substitution within 2-3 weeks plus taking any protective measures that can minimize the damage. This balancing of recovery capability and functional inventory will help to maintain competitiveness. More generally, instead of adopting continuity-first systems permanently in fear of the "next big one", we recommend a combination of choosing *competitiveness-first systems* and building *supply-chain-continuation capabilities* during the normal time between disasters.

There are certainly exceptional cases in which we need to pile up inventories "just-in-case" – *national security goods* whose inventory decisions go beyond economic calculation; *emergency goods* for which rapid demand increases are driven by the disaster itself (e.g., certain medicines, medical equipment and face masks in the COVID-19 pandemic). But we should not confuse such *special* goods with *ordinary* goods. For the latter, we still recommend the capability-based approach, rather than "just-in-case" buffer-based approach.

We do not deny the value of inventories nor the value of BCP related to inventory levels. We simply argue that relying on "just-in case inventories" driven by BCP prepared in advance is not effective when disasters are emergent and characterized by highly unpredictable events. Similarly, a reactive shift to dual sourcing is non-adaptive and impedes competitiveness.

2. Supply Chain Flexibility vs. Unilateral Localization

We can also apply our capability-based approach to the issue of a globally dispersed supply chain versus locally independent ones. When we apply the competitiveness-first principle, a global firm should choose a competitive pattern of supply chain, which can be either *global* (extended internationally) or *local* (compact within a country or only spanning the borders of geographically contiguous countries) depending upon the product's or its components' bulkiness, market size, government policies, etc.

Whichever the case, once a global disaster happens and the supply chain is damaged in one or more countries, it must be quickly transformed from global to local (e.g., factories in country A start substitution domestic production when country B's exporting factories stop production for some time), or from local to global (e.g., factories in country A start substitution production exports when country B's domestic supply chain stops for some time). Either way, this implies that what we need in the era of global disasters may be *flexible global-local supply chains* that can quickly switch from competitiveness-first mode to continuity-first mode, or between global and local types.

In other words, we do not agree with the popular arguments that global supply chains involving emerging nations, developed during the post-Cold-War era, should be changed permanently to more local ones. We would rather argue that the 200-year-old principle of comparative advantage and benefits from trade should be respected as the criterion for our competition-first choice of supply chains.

Again, permanent localization may be the case for certain national security goods or emergency goods, but from business-economic point of view, what we recommend for ordinary goods is the aforementioned approach of flexible global-local supply chains, which are capable of temporary switching between global and local modes (and vice-versa) in times of emergency.

3. Ongoing Supply Chain Learning vs. Business Continuity Planning (BCP)

In the case of core firms in a given supply chain (e.g., assembler or core component supplier), there are two options. One is to establish a specialized Business Continuity Planning (BCP) unit, which prepares the "just-in-case" continuation plans for all production or logistic facilities of the firm and its supply chain. The other choice is to go to the organizational unit that is already in charge of daily flow control and process improvement at the affected site, such as the production control department, and set up an emergency supply chain continuation unit there, drawing on their continually updated knowledge to speed up adaptive responses to the disaster.

Recall that at Toyota Motor Corporation, when a major disaster happens, its supplier recovery assistance center is set up in the production control department, which is in charge of controlling and improving value-added streams of its supply chains, rather than in a specialized BCP department. Through frequent assistance to its suppliers' factories, this flow-oriented unit has deep knowledge about the supply chains and the suppliers' production processes, so the company can quickly move and provide effective recovery assistance to the suppliers.

Certainly we do not disagree with setting up a "Business Continuity Planning" (BCP) unit that makes deliberate business continuation plans in the era of disasters. But to the extent that actual disasters are in many aspects unpredictable, we do not agree with the idea of totally relying on specialized BCP units. We think that applying the knowledge gained from *flow improvements* (kaizen) in normal time and applying it to achieving *flow continuation* in emergency time are not two separate tasks but a single integrated agenda.

Broadly speaking, the capability-based approach we propose differs from the BCP that often constitutes firms' first-wave response to disaster-driven supply chain disruptions. While BCP is based on identifying potential supply chain vulnerabilities vis-a-vis various possible disasters and preparing a mitigation plan, we see this approach as overly focused on the "last war" and overly optimistic about being able to forecast future disasters with precision. The history of disasters affecting supply chains indicates an increasing frequency of major disruptions – and the reality that the peculiarities of each new disaster are likely to overwhelm whatever plans or preparations firms make. We certainly do not disavow the importance of preparing for the future. But rather than BCPs for specific anticipated disasters, we advocate for developing "supply chain continuation" capabilities to respond quickly and creatively to whatever new disaster presents itself.

Amid an unfolding disaster, choosing wisely among *recovery, substitutive, and protection* responses is crucial. The time period between disasters is when these capabilities can be developed further. The combination of capability development in relatively quiet times plus consolidating what is learned after deploying them, via real-time responses to disasters, is the best path, we argue, to achieving the supply chains we will need in a post-pandemic world – either competitive or resilient in the short-run (depending on current challenges) but competitive **and** resilient in the long run.

This ongoing capability-building approach requires that management and front-line personnel, customers and suppliers at all tiers of a supply chain work collaboratively to solve new (minor and major) problems as they emerge to be ready to cope with new, unexpected disasters. The potential negative environmental consequences of global value chains are particularly sensitive in this regard. Reactive responses, even if major and well-funded, that follow after an environmental disaster will always be "too little, too late" in comparison with efforts to eliminate waste of all sorts in ongoing supply chain operations to combine "green and lean" outcomes.[10]

[10] See, for example, Rothenberg et al. (2009).

Implications for post-COVID-19 Supply Chains

Specifically with regard to COVID-19, we wish to distinguish our viewpoint from current media and public commentary about supply chain fragility and brittleness, in several regards.

- First, we believe no firm, nation, or other entity could have fully anticipated the magnitude and speed of the current pandemic's impact. COVID-19 affected the whole world so quickly, forcing the shutdown of much of the world's economic activity, creating a huge demand shock that almost immediately dwarfed the early worries about a supply shock when China was hit hard. Calls for more supply chain continuity are understandable and warranted but must be made with an understanding of the limited capacity of advanced planning for any supply chain configuration to have absorbed this pandemic's impact smoothly and effectively.
- Second, mindful of the huge attention to shortages of critical medical supplies in the most infectious early stages of the COVID-19 virus (e.g., Personal Protective Equipment (PPE), tests and swabs, ventilators), we distinguish *emergency goods* (aka *special* goods) from the vast majority of *normal* goods circulating through global supply chains. Emergency goods should be stockpiled by governments in sufficient quantities to deal with surge demand in a public health crisis, as long as they are not subject to rapid obsolescence. Normal goods should maintain inventory levels consistent with customer's regular requirements and the realities of global competitiveness, albeit backed up by the three capabilities *(protective, recovery, and substitutive)* identified above. Inventory practices for emergency goods amid a crisis that creates a demand spike for those goods will need to change dramatically, regardless of previous stockpiling; but this does not mean that normal goods inventories need the same adjustment.
- Third, we reject the dichotomous nature of the predominant public discourse on supply chains in the midst of the COVID pandemic. Supply chains are not either "efficient" or "resilient" but

constitute a mix of efficiency and resiliency that varies (and can be managed) over time. “Lean” principles support elimination of “excessive inventory”, **not** “zero inventory”. Boosting inventory stocks automatically can easily create excessive buffers that won’t boost continuity (i.e., if problems are hidden) yet will impair competitiveness. Where a “Just-in-Time” flow-oriented pull system is disrupted by disaster, we disagree that the best response is shifting over to a “Just-in-Case” forecast-oriented push system. When a single source supplier is quickly depleted or taken out of action by a disaster, we disagree that the answer is having dual sources and geographic dispersion for all components at all times. The key to the ambidextrous approach we advocate is a firm’s (or nation’s) ability to pursue simultaneously goals that others regard as imposing tradeoff-forcing constraints.

- Fourth, we have argued strongly that the time between the appearance of a disaster in a given geography and when it affects a firm’s manufacturing site or supply chain route is a valuable period for taking preparatory action for protection, recovery, or substitution. We also noted that a characteristic of COVID-19 as an “invisible/global” disaster is that the pandemic hit the whole world more or less at once. This complicates choices among global vs. local supply chain options as both may be simultaneously affected by the coronavirus, which is less likely with a “visible/regional” disaster with a distinct geographical impact. Still, given the variation in when the peak of infections hit various countries, different rates of “flattening the curve” that can be linked to the mitigation strategies of different nations and within-country jurisdictions, and growing ability to anticipate the conditions causing infections to rise again (e.g., cold weather that will bring people inside; holidays when families will be pulled together), it is likely that firms, planning for their own manufacturing sites and supply chain routes, will be able to find opportunities for preparation in advance of facing a rise in infections that directly impacts them.

While our focus has primarily been on recommendations for firms, we also see clear implications for national and local governments seeking better preparedness for public health emergencies. There is certainly a role for governments to play in stockpiling emergency goods and making sure that there will be capacity available for local production of such special goods. We would urge this imperative for local supply be pursued via developing substitution production options at the existing sites of local firms rather than building and holding industrial capacity in mothballed reserve for emergencies. We also see an important role for governments in making policies that broadly support this capability-building approach to disaster risk. Since supply chain continuation capabilities work in concert with a firm's operational capabilities, policies that support worker training and skill development, promote infrastructure development for logistical efficiency, or that incentivize regional collaboration among large firms and their suppliers in terms of knowledge-sharing about each other's protective, recovery, and substitutive capabilities can also serve to increase disaster readiness.

Our goal has been to suggest a more nuanced sense of why the current calls for dichotomy-based supply chain reforms (e.g., "Just-in-Time" to "Just-in-Case"; single- to dual-sourced; global to local sourcing) can set back the goal of building truly resilient **and** efficient supply chains that can respond with agility to the emergent phenomena of a new, unanticipated disaster. We urge that researchers explore these capability-based approaches to disaster management more fully, beyond the case studies that provide our evidence. The post-COVID period will provide ample opportunity for data collection -- and very likely more surprises and chances to learn as well.

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