COVID Information Commons (CIC) Research Lightning Talk

Transcript of a Presentation by Zachary M. Boyd (Brigham Young University), April 15, 2022

Title: LEAPS-MPS: Structure and Dynamics of Global Supply Chain Networks

Kelly Dunning CIC Database Profile

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Transcript

Zachary Boyd:

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Thanks everyone else for your presentations. It's a pleasure today to share my results on "Structure and Dynamics of Global Supply Chain Networks". So unlike the previous projects, this is a two-year NSF project that we had some prior work for, but so far we're three months into the official project and I, as a mathematician, I'm doing things that are a little bit more theoretical compared to the previous speakers. But I still think that, you know, we're answering interesting questions and welcome collaborative ideas at this point since we're earlier in the project so far. I'd also like to acknowledge my great collaborators Kayvan Lavassani who's in the Business School at North Carolina Central University and has helped ground a lot of the questions that we're asking to make sure they're consistent with real actual business sense. And then my student Jason Vasquez, who's done a lot of great things too.

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So the major goal of this project is to increase understanding of breakdown and recovery of global supply chains particularly, in light of the COVID pandemic. While everyone knows that COVID has adversely affected our supply chains, how to model this change is much less understood. Particularly as the challenges are multifaceted and changing time. For example, in the early days of the pandemic, we faced an urgent need for items such as masks and ventilators in unprecedented numbers. As the crisis wore on, we began to focus more on general supply chain difficulties such as the limited or unpredictable availability of everyday items. In the coming years it seems clear that supply chain professionals are planning a radical reorganization of their supply chains to try to mitigate the risk of future events like this. For example, by including more domestic based production or intentionally placing production in multiple foreign locations in case of localized problems.

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Of course much has already been known about global supply chains before the pandemic. The problem is that existing knowledge is not well adapted to this kind of a situation. For example, firms in recent years have made fabulous gains in predicting short-term demand fluctuations and optimizing for cost, for example. On the macro level, economists and complexity scientists have mapped out and traced shock propagation through the network dependencies between countries and industries. And finally, following the 2008 financial crisis, notions of systemic risk in finance have been very well developed. What is less understood is - and that's needed for COVID - is an understanding of how supply chains can recover as a system, after heavy disruption. No single firm currently has the capability or data to answer this question because of their focus on their own more localized needs, or at least needs specific to their firm. Indeed, it is even unclear what policy actions are available that might help with the problems that we're facing. A particular weakness of the existing knowledge phase is that most relevant modeling is about small, week to week demand forecasting under, you know, regular life fluctuations as opposed to the high intensity disruptions that COVID has caused. And they continue to change. My project is in part about developing notions of systemic risk grounded in the patterns of dependency between actual firms so we can start to understand what tools we need to ask this question, what data would be useful and what actions could plausibly be helpful.

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So I'll describe the major data source that we found the most useful so far. We've collected the largest global supply chain map in existence as far as we know and are analyzing it. Public firms all over the world are required to disclose their major suppliers and customers, which we've used to glue together our map.

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While we may imagine a supply chain as being a tiered structure as in this visualization, once you get to the global level of many intertwined supply chains with many firms, the complex dependencies really yield a tangled soup of connections as visualized in part here for the auto industry. Note that there are some dominant firms, I've sized the nodes by what we call their 'centrality' and many many less central ones that actually get so small that you kind of can't see them in this visualization. We've colored the nodes using community detection, which highlights that there are business ecosystems that fundamentally depend on each other and work in the same space as each other. These ecosystems also do have something to do with geographic distributions. If you look at some of the names, you'll see a blue blob that contains for example, Toyota, which is, you know, separate from some of these green firms which include the Chrysler supply chain. And so there's certainly some geographic structure in these large extended supply chains as well.

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So far, we've succeeded a fair amount in just modeling disruption in this network. And the way that we've focused so far is just looking at the long or short term deactivation or diminished activity of some firms. So from a graph theory perspective, this means no deletion. In some simulations, we did random deletion, which kind of corresponds to the widespread indiscriminate destruction. In others we're trying to actively target large and central firms, which is an attempt to get a kind of a worst case scenario.

We've also varied how many firms were subject to disruption as well as modeling some specific scenarios such as the cessation of global international trade for a brief time or a U.S. - China-specific trade disruption. Some of our models have also included this idea of cascading failure, which is this important supply chain idea that if one firm fails in the short term or otherwise has to reduce its operations due to outbreak, some firms that it supplies will also have to reduce their operations or shut down in the near term. To measure the overall effect of these disruptions, we used a path counting metric, which captures the idea that resources need to be able to flow vertically up or down the supply chain from distant supply chain connections like in the bottom of this figure, representing basically kind of raw materials, all the way up to critical customer facing terms of firms. We focused on medical suppliers for example. The outcome that we measured and reported on the most that we found useful was in terms of the percent of these critical paths through the supply chain that were still usable after various kinds of shutdowns. Sometimes the disruptions were such, that many of the critical paths remained operational, as in the left figure where we kind of visualize cutting through in such a way that you can still have some vertical paths, whereas other disruptions were in the right place to essentially knock out all of the critical paths and shut down an entire critical industry in the near term.

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An example of the sorts of results that we get from this sort of analysis is our list on this page. So for example, if we make the sunny assumption that cascading failure is negligible - so firms can shut down but this doesn't necessarily shut down downstream firms directly - in this case the global supply chain looks surprisingly robust to short-term unavailability of randomized firms. So, for example, up to 27 percent of firms could randomly fail before 80 percent of medical suppliers were paralyzed, or in other words, unable to get things that they needed. In contrast the worst case scenario, where very central or large firms fail, was much worse. Only 3 percent of targeted firms needed to fail before 80 percent of medical suppliers were paralyzed. There were also some key industry country pairs such as US or China biotech that were especially critical for the medical suppliers. If instead, we assume a strict cascading rule, which is more pessimistic, 25 percent of firms actually end up having the property that if they are removed, at least 10,000 other firms become inoperable in the short term until they can establish new relationships or before the original firm comes back online. And so the failure of one of these firms will paralyze all medical supply firms, in short. The reality of the situation is likely somewhere in between these two scenarios and we're working on this parameter estimation problem of how much cascading is really realistic for scenarios that we care about. As a last example, we looked at the U.S. military supply chains which, you know, historically have tried very hard to protect themselves against intervention. And we posed the question of how much risk mitigation is really possible by protecting only, for example, domestic or treaty partner firms through government action. We found that without cascading, some protection really is possible, but when you include a significant chance of cascading, then problems in non-treaty countries can quickly have devastating effects in the larger supply chain regardless of your own individual actions.

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Okay, so there, you know, our simulations, no matter how complex, will never be as sophisticated as real life is. Here are some key directions that I see coming up next for us, and possibly for others, to expand our understanding further and eventually help with supply chain recovery and understanding what the future can hold if we act a certain way. So first, we need to integrate the multiple layers or perspectives

of the supply chain. This is especially critical when we talk about transportation, which in recent months has been more of a problem than firm shutdowns. So these are two different networks where you have a firm interdependence network and you also have a transport network that needs to be integrated. Second, we need to understand what actions are most helpful to get a supply chain network to transition back from low operating capacity to high. And then we need the right measures of various aspects of disruption from real life scenarios like COVID, or Suez Canal blockage, or the conflict in Ukraine, and so forth. And these will happen on various time scales and you know these inform the real decisions that supply chain experts are trying to make at this time to understand how to reorganize, you know, the world, basically, to be prepared for the future and provide less risk for all of us.

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So thank you for your time. I'll answer the chat questions and I'm also happy to talk over email about collaboration possibilities, thank you.