COVID Information Commons (CIC) Research Lightning Talk

Transcript of a Presentation by Zachary Boyd (Brigham Young University) October 10, 2023

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

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Transcript

Slide 1

I'm excited to be back here and talking again. I think this presentation is almost the opposite of the previous presentation. We don't have - we don't have anything wet or gooey in what I'm doing. I'm a math professor and I'm focusing basically on understanding the mechanisms of the supply chain breakdown and supply chain reorganization which obviously is really relevant to COVID as well as other disasters.
I'm presenting joint work with several people - this is a multidisiplinary team. Nitin is a business professor, Sean and David are computer scientists. Tyler Burrows is the Ph.D. student who really exercised a bunch of leadership on this project, so huge credit to him for this work.
I'm going to present the results of the mathematical model. It's an agent-based model, which in the realm of mathematical models tends to be very detailed. You can bake in all of the assumptions that you can think to make and really trace out the consequences of those assumptions throughout the system. The take-home message is going to be, basically, about the role of managerial decision-making in times of crisis versus in times of stability and how to think about the tradeoff between different policy options within firms.

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To start off, just to summarize a little bit of what I already said - this is basically all based on a novel detailed model of supply chains. It is different from a lot of other models which really assume that firms are hooked in a serial manner, one to another up through the global economy.

We know this is a really unrealistic assumption. Firms and the global supply chain really form this complex web of interactions and often it even has cycles with firms eventually relying on the products they themselves produce far down the stream in complex ways. We thought it was important to introduce possibilities of more complex structures to the supply chain - more than just a chain. We also have included various complex dynamics and nonlinearities, especially accounting for the way that managers might think about things. The managers in this model are mostly risk minimizers. They really want to deliver on their promises to other companies and to their superiors. They want to choose suppliers and order from them in a way that really guarantees their output to be reliable. It pulls in a lot of big tools from engineering traditions like Computer Science and Mathematics. So some of the big themes you're going to see in the next few minutes is the relationship between the structure of the relationship between firms and the behavior of those firms and especially the role of policy. Here, I don't really mean public policy which is kind of what a lot of COVID talks about in terms of policy. This is firm policy - this is how firms act and the way they make their decisions. We demonstrated, at least within the assumptions of this model, that diversifying the supplier base (which is a big theme for firms in recent years and especially since the pandemic) - firms are thinking about more ways to diversify the suppliers that they source from to try and de-risk themselves. We've shown that there are both risk-reducing and risk-increasing effects to these decisions that firms make and that the policies firms choose can affect this outcome. This work is forthcoming in one of the major computer science and control theory conferences. A patent is also pending.

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Just to give you a schematic - I'm not going to ask you to understand the guts of a large mathematical model here, that's not the point - but just to give you an idea of kind of what's going on under the hood, we have here a graph of a supply chain. This is just a tiny fragment of one medical provider that might need medical supplies from more than one firm. We treat the firm as input and as having inputs and outputs. We know that firms have outputs, right? They have to produce physical goods in many cases and pass them downstream in the supply chain, but there's also information flowing upstream. That's the other important channel here because information is unreliable and uncertain and often delayed in times of crisis as well as in times of stability. We have information flowing backwards up the supply chain about what is wanted in the future. Firms have to make orders and make contracts and push physical goods downstream. One of the main negative behaviors that we focus on is what's called the bullwhip effect, which is this phenomenon that even in times of stability when when user demand for products is fairly stable downstream, little fluctuations in demand get amplified the further upstream you go in the supply chain.

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There's two parts of this. First, material orders tend to be more variable than demand signals. There are a few reasons for this. It's actually kind of contentious what the most important reasons

are, but basically, firms may want to hedge their bets and maintain inventory, they're uncertain about the future, they want to make sure they can deliver on their promises.

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Then, then when the second firm in the line has to hedge on their bet, then the third firm has to hedge on that hedged bet, and it goes upstream and and kind of gets worse and worse. The uncertainty magnifies. This can be really disruptive. I've certainly heard people say that semiconductors are like this where it can be very feast or famine when when you anticipate that there will be a need, then production has to ramp up like crazy. Then, over-production can sometimes happen.

Slide 6
It's just really disastrous. We're investigating the role of policy in this context and really managerial control and adaptability. The main thing I'm going to show you in this presentation is whether the manager takes the stance of being very flexible about who they order from in times of uncertainty or whether they just continue business as usual. Of course, there's a whole spectrum of how adaptive people can be, but basically we pinned down that in times of stability, managers who fit the assumptions that that we've integrated from the literature here tend to make matters worse in terms of the bullwhip effect by over-adapting to noise coming from downstream that they interpret as signal.

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But, as I'll show you in a coming slide, in times of crisis the picture is really different. For the purpose of this presentation, we're thinking of two policies: one where a firm has, say, four different suppliers of a critical ingredient and they - just maybe due to long-term contractual requirements or company policies or managerial decision-making - they always source the same proportion of what they need from all their suppliers and hope that their suppliers come through. Whereas, on the right, if you have a lot more managerial liberty or you believe that you might be entering a time of crisis, then there's this variable ordering policy where the manager has to use past behavior and forecast of the future to guess which of their suppliers are going to come through for them and how much they're going to come through and adapt their orders in such a way as to try to guarantee that they're going to be able to deliver on their own promises downstream from themselves.

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Here's my one big data slide that is supposed to illustrate what happens. In this model, there's a lot going on. Let's focus on this upper left quadrant. Here is over time and just for simplicity, we're tracking across four tiers of the supply chain. You should think of firm zero as being direct to customer, firm four being very removed from the immediate customer. The customer of firm four is firm three. And the customer of firm three is firm two, and so forth. What we see is there's

two periods we put into this particular simulation. The flat parts are periods of relative stability when there's no crisis, there are fluctuations but it's kind of calm. Then, there are these periods of shock. In this slide, we included a demand shock where suddenly it's (either in reality or in perception), a lot of what firm zero produces is needed. You can imagine this to be masking equipment, respirators, toilet paper, whatever you think important in times of a pandemic.
What you see in the structural case - this is where the firms don't really make an - they're either stuck in their contract or they feel unable to adapt or they don't think a real crisis is happening, the demand shock goes up. You see the blue spikes right up and the blue's kind of hidden by the other curves here, unfortunately. But there's very little wobbliness in the blue, but by the time you get all the way up to level four, the purple firm, the perception of demand that firm four experiences is all over the place. They have really high uncertainty. The important thing - let's look at this second big shock here. It takes from about time 200 to time 350 or so for things to settle down for firm four. After a disruption, it takes a long time for them to recover and get back to their stable lives. Now, if we look over on the other side here, in the policy setting, this is where the managerial agents in the system have more freedom to make decisions and alter policies in the moment based on the idea that a significant change is occurring. If you look in the periods of stability, there's more bullwhip effect - there's more just totally unfounded variation in perceived demand. But if you look in the time of crisis, there's still this big shock up and down. Purple is definitely the worst. Green firm - tier three is also pretty bad, but firm one is experiencing much less and is recovering quicker from the shock. The point is - if you look at firm four, the far upstream firm, it's seeing disruptions about time 220 or so, but the recovery is by about 275. The recovery is something like three times faster in the case of a policy situation where the manager is at each time point estimating what might be happening and trying to adapt. So the take-home of this in terms of policy is that there's a trade-off between these really stable approaches that maybe have long-term contracts and and keep firms locked into behavior or bureaucracies or other procedures that keep people locked into behaviors. In times of true stability, these can be really advantageous, but in times of crisis, there's the trade-off that you might not take the right steps early or even in the middle of the crisis to recover. This is illustrated in this diagram. And this is the last big figure that I'll that I'll talk about.
Of course there's a whole spectrum of possibilities between a fully structured approach and a fully manager decision-making driven policy. I mean, this is just one model, I certainly don't want to over interpret it in terms of real life. Real life is vastly more complex than even this pretty complex model. But this trade-off between systems that lock managers in so they don't over-interpret problems that are not real problems, and the ability to react when an actual problem occurs without having to be too slow in their response time is kind of the take-home message for non-math people from this model.

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Anyway, that's all.

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I'm happy to answer questions I'm aware I've taken up my time, but full credit to to Tyler for exercising big leadership on this project. I'm happy to be contacted by others who have questions more at the PI level as well. So thank you!