Supply Chain Bottlenecks in a Pandemic

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Introduction

- Goods and services reach final consumers via often complex supply chains
- Disruptions at any point in the supply chain might prevent the final good being produced
- In a pandemic these supply-chains can become significantly disrupted (e.g., Financial Times, 2020)
- Governments have enacted wide reaching policies to stop the spread of COVID-19 inducing widespread business disruptions
- How can policymakers keep key supply chains functioning?

Research Questions

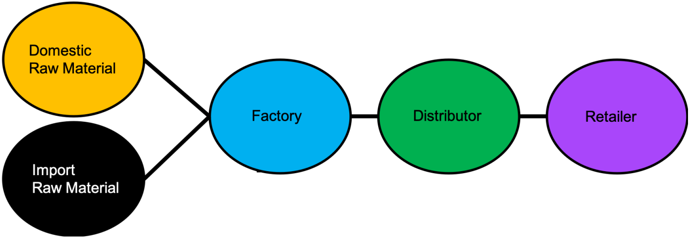
- Q1: **Which firms are essential for meeting demand in a crisis?**
  - e.g., which firms are needed directly or indirectly for ventilator demand to be met?
- Q2: **Could a government restore failing supply-chains by just targeting essential firms?**
- Q3: **How can data on business to business transactions be used to identify essential firms?**

Our Proposal

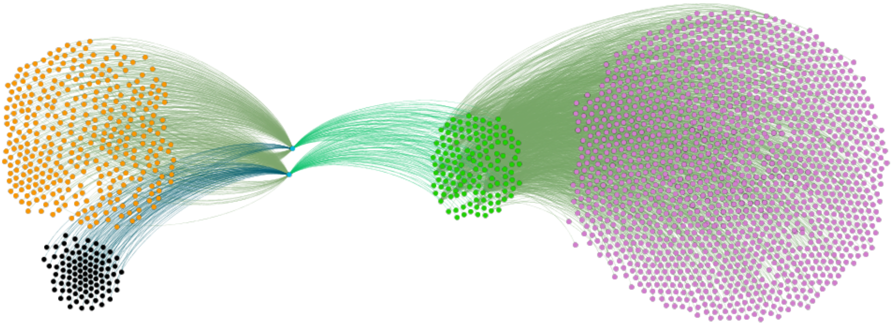
- A definition of what makes a firm essential
  - A firm is essential if demand for key goods at current prices cannot be met without it producing
  - We show that essential firms act as bottlenecks in supply chains
- Scalable network algorithms to identify bottlenecks in a supply chain:
  - Input: business-to-business transactions
  - Output: bottleneck firms
- Operationalising the algorithm
  - Proof of concept: Adapted from previous work studying Ugandan economy 2010-2015 (Carvalho, Elliott and Spray, In Progress)

A Real World Supply Chain

- We start with an example from Ugandan business-to-business transaction data adapted from Carvalho, Elliott and Spray (In Progress)
- Consider the following actual supply-chain operating in Uganda in 2015
  - There are only two factories
  - Each use two inputs: one sourced domestically, one sourced internationally
  - Each sell to distributors who then sell onto retailers



Bottleneck Example



2 small factories (blue):

- buy inputs from 340 suppliers (orange)
- sell to 135 firms (green)
- sell to 1548 firms (purple)
- import from 96 foreign suppliers (black)

Source: Carvalho, Elliott & Spray (in progress)

Bottleneck Example

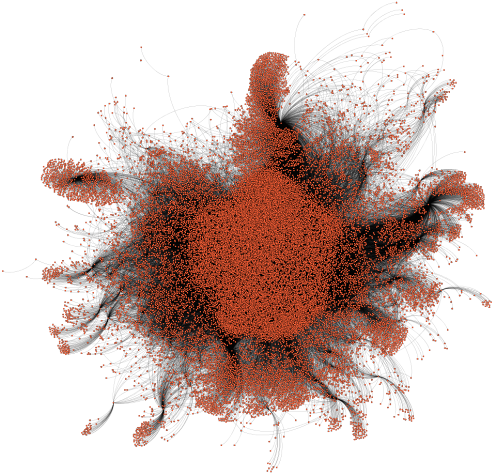
- Over 2000 firms depend on chain with 2 essential firms (blue nodes)
- Goods flow from raw material producers, to the manufacturers, to the distributor and finally the retailers
  - These flows enable successful production
- If either of the manufacturers can't produce
  - the other manufacturer cannot take up the slack;
  - these flows are necessarily diminished and output drops;
  - in this case, the manufacturers (blue nodes) are both bottlenecks

Difficulties

- This was a very simple supply chain, many supply chains are much more complicated
- Firms often multisource, but from the same pool of suppliers
- Supply chains interact with each other—for example one inputs often features in the supply chains for several different types of goods
- How does all this affect which firms are bottlenecks?
- How can we estimate the ability of firms to "take up the slack" if a competitor can't produce?

Need a scalable way to take firm-to-firm transaction data and quickly identify which firms are essential

Problem: how to convert economy wide data into set of bottlenecks?

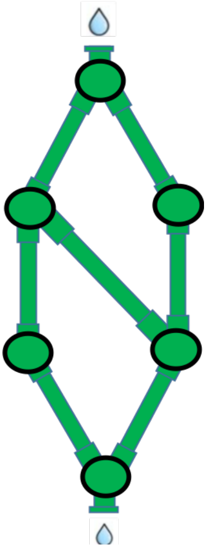


All firm-to-firm connections in Uganda

Source: Carvalho, Elliott & Spray (In Progress)

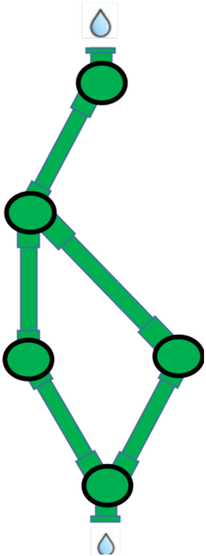
Proposed Solution: a simple analogy

- Consider a system of pipes, the capacity of each pipe, and the capacities of the junctions where the pipes meet
- Suppose water travels through the pipes from a source to a sink
- Given the capacity of each pipe and each junction, and the structure of their interconnections - how much water flows through the system?
- Well developed area of engineering / computer science (known as maximum flow problems)



Proposed Solution: a simple analogy

- What would the maximum flow be if we remove a junction?
- Is it lower without the junction? If so, we call it a bottleneck



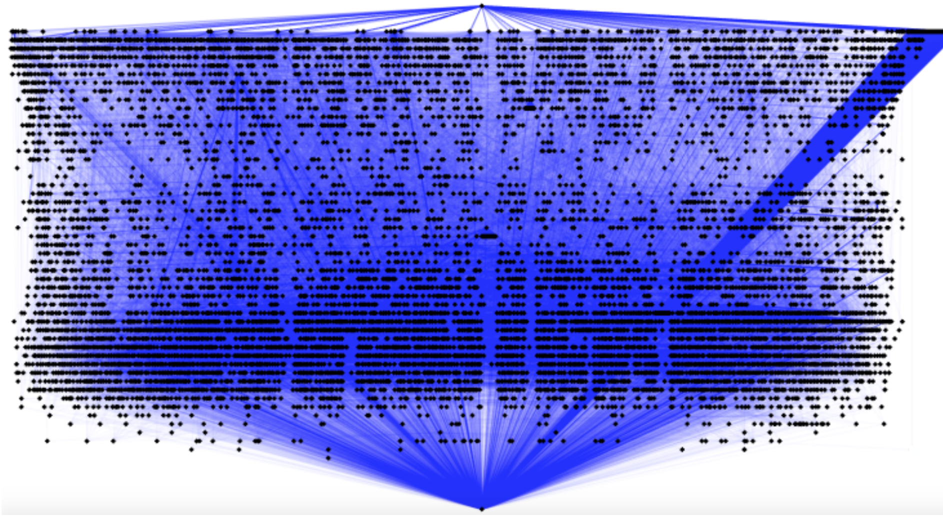
Back to supply chains

- The analogy with supply chains is as follows,
  - the source corresponds to raw materials
  - the sink corresponds to final demand
  - the capacity of a junction corresponds to the capacity of a firm
  - the capacity of a pipe corresponds to the capacity of a supply relationship
- Bottleneck junctions correspond to bottleneck firms
- Moving to a production setting we need to represent flows in units that are conserved—like water is in the flow network
  - This is possible by thinking about intermediate and final goods as bundles of raw materials

Identifying Bottlenecks (in practice)

- To run algorithm we need:
    - Data on firm-to-firm transactions
- But problems remain:
    - We can't have cycles, and there are a few in the data
    - We don't know the technology used by each firm
      (which different types of inputs it requires and in what ratios)
    - We don't know the capacities
- Solutions presented in Carvalho, Elliott & Spray (In Progress):
    - Prune edges using a Feedback Arc Set (FAS) algorithm
    - Infer technology using previous trades and a hierarchical clustering algorithm
    - Use the history of trades to assign capacities

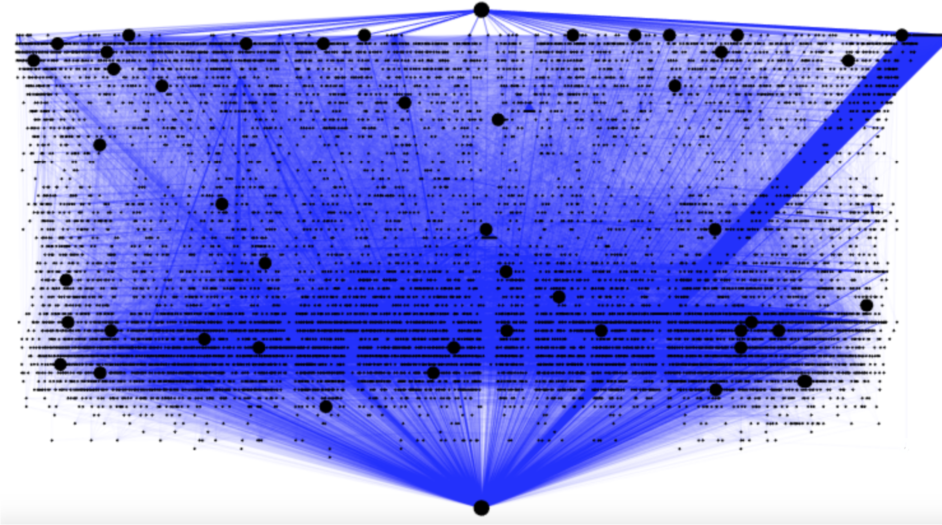
Proof of Concept: Full Network After Pruning



All firm-to-firm connections in Uganda

Source: Carvalho, Elliott & Spray (in progress)

Proof of Concept: Set of Bottleneck Firms



All firm-to-firm connections in Uganda

Source: Carvalho, Elliott & Spray (in progress)

Set of Bottleneck Firms

- We identify an average of 50 critical firms every semester (out of 37K)
- Bottlenecks status is persistent:
  Prob(Firm i bottleneck at $t|i$ bottleneck at $(t-1)$) = 0.77
- Sectors with greatest number of bottleneck firms:
  - Agriculture, Food and Drinks Supply Chain
    - Primary Production
    - Manufacturing Processing
    - Wholesalers
  - Natural Monopolies
    - Energy Generation and Distribution
  - Some Financial Service Sectors

Adapting Methodology to Study Covid-19

- What we need:
  - Business-to-business transactions
  - How much of which goods are deemed crucial in the context of the pandemic
- What we can provide:
  - The set of essential firms for this production to happen
  - Forecasts of the economy-wide impact of shocks to specific firms, sectors or to imports
  - A toolkit for studying intervention counterfactuals