Experiments on "Networks of Intermediation"
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Originally, the project had two parts, part one was on price discrimination and the the second part was on heterogenous valued paths. We have made progress on both parts – we have developed and analyzed theoretical models of both problems. But for the experimental side we decided to focus our energies on information and pricing in networks. A major part of these experiments were published in the paper titled, *Trading in Networks: Theory and Experiments* in the *Journal of European Economic Association* in 2017. The project and the paper published are joint work with Syngjoo Choi (Seoul) and Andrea Galeotti (EUI).

I note that the JEEA paper was discussed at length in my final report on the project titled, *'Experiments on Financial Networks'*, which was submitted to the Keynes Fund Managers in April 2017. The present report covers experiments that were not included in that published paper but are included in a separate paper titled, 'Trading in Networks: Uniform Prices'.

I would like to add that these two projects, funded by the Keynes Fund, were an important input in on-going my European Horizon 2020 Award that studies large scale experiments. The award is worth 2.6 million Euros, and involves collaboration with economists, social scientists, mathematicians, and physicists across 7 universities (Alto in Finland; Cambridge and Oxford in the UK; Carlos 3, Valencia and Zaragoza in Spain; University of Amsterdam in Netherlands).

1 Motivation

Supply, service and trading chains are a defining feature of the modern economy. They are prominent in agriculture, in transport and communication networks, in international trade, in markets for bribes and in finance. Goods and services pass through individuals or firms located along these chains. The routing of economic activity, the earnings of individuals and the efficiency of the system depend on the prices set by these different intermediaries. The aim of this project was to understand how the network structure of chains shapes market power and thereby determines prices and efficiency.

2 Framework

To fix ideas, consider pricing in a transport network. A tourist wants to travel on the Eurostar from London to Paris to see the Louvre. The first leg of the journey is from Home to St. Pancras Station, using one of a number of different services, such as taxi companies, bus services and the Underground. Once at St. Pancras Station, the only service provider to Paris Nord Station is

Eurostar. Upon arriving at Paris Nord, there are a number of alternatives (bus, Metro and taxi) to get to the Louvre. The network consists of alternative paths, each comprised of local transport alternatives in London and in Paris and a common node (the Eurostar Company). Each of the service providers sets a price, and the traveler picks the cheapest 'path.'

These examples motivate the following model. There is a source node, $\mathcal{S}$, and a destination node, $\mathcal{D}$. A path between the two is a sequence of interconnected nodes, each occupied by an intermediary. The source node, the destination node and all the paths between them, together, define a network. The passage of goods from source to destination generates *value*. Intermediaries simultaneously post a price to get a share of this value; the prices determine a total cost for every path between $\mathcal{S}$ and $\mathcal{D}$. We assume that the good moves along a least-cost path and an intermediary earns payoffs only if she is located on it. Posted prices are the norm in transport and communication networks. We characterize the Nash equilibria of the pricing game.

A node is said to be critical if it lies on all paths between $\mathcal{S}$ and $\mathcal{D}$. In the benchmark setting, with full information and homogenous paths, the main finding, that combines the theory and the experiments, is that a trader or a node makes profits if and only if it is *critical*, i.e., it lies on all paths between the source and the destination.

Choi, Galeotti and Goyal (2017) assume that all paths generate equal value and that traders can perfectly discriminate in setting their prices. In important applications of interest these assumptions are violated. We focused our attention on the issue of price discrimination:

- A service provider may not have full information on the origin and destination of a consumer or a trade. This may oblige the service provider to set uniform prices for a range of services. Or, there may legal restrictions that force an intermediary to set the same access price regardless of the origin and the destination of a consumer. These considerations call for a model where intermediaries price uniformly

We extend the model in Choi, Galeotti and Goyal (2017) to the case where intermediaries set a price without knowing the network origin and destination of trades. That is, all traders simultaneously post prices and once prices are set, a buyer-seller pair is picked at random from the set of all traders. Given a profile of prices, a trader faces the following trade-off. A higher price raises the payoff if trade does take place; this trade is likely to be for close by buyer-seller pairs. A lower price creates the possibility for longer distance trade, between farther away buyer-seller pairs. We study the implications of this trade-off for pricing, division of surplus and efficiency.

3 Findings

We start by developing general properties of equilibrium for arbitrary networks. We then focus on ring networks and on networks with cliques of traders. We obtain two general insights. One, as we expand ring size, equilibrium with lower prices arise but there is a limit to the price fall: in particular, the lowest positive price supported in equilibrium is such that there is a break down of all trades in which traders are more than distance 4 apart. The second observation is about the role of critical traders: in a setting with uniform price, there exists a symmetric equilibrium with large positive prices and trade, even in a ring network. That is, even when there are no critical traders, there are plausible equilibria where intermediaries earn a substantial profit.

Our aim was to to study the impact of networks on pricing, division of surplus and efficiency of trade. As in our earlier work, multiplicity of equilibrium makes a clear cut theoretical prediction difficult. The principal findings of our experiments were as follows:

- **Efficiency:** The level of efficiency declines in the size of networks and decreases in distance within a network. Ring 4 achieves full efficiency and Ring 10 has a lowest level of efficiency. In Ring 6, the frequency of trade drops by around 40 percentage point from distance 2 to distance 3. In Ring 8 and Ring 10, probability of trade drops sharply, going from distance 3 to distance 4 it drops by 35 percentage points.

- **Pricing:** the size of networks has significant influence on pricing due to the tension between serving only local markets and serving markets over longer distances. Putting aside Ring 4 where price competition is dominant, average prices decline in the size of ring networks: 61 in Ring 4, 42 in Ring 8, and 38 in Ring 10.

These findings are contained in a discussion paper titled, 'Trading in Networks: Uniform Prices'.

4 Contribution and related literature

Our model offers a generalization of the classical models of price competition (a la Bertrand) and the Nash demand game (Nash, 1950) to a setting with multiple price-setting agents, in which coordination, competition and double marginalization are important. In recent years, there has been a great deal of research on these questions. There are, broadly, three protocols for "price" formation: auctions, bargaining, and posted prices. As we study a model with posted prices, our paper falls in the third strand of work.

The theory and the experiments go beyond the state of the art in two dimensions: one, we develop and analyze a new theoretical model where the exact demand is unknown, and two, we conduct experiments on this model.

5 References

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