Research statement

Structure: *introduction - epidemiology - information transmission - network security*

My research interests lie broadly within the scope of applied economic theory, with a special interest in understanding the role of social linkages. They play an indispensable role in many situations of economic interest including political campaigns, advertising, and viral transmission. How do social networks determine the spread of information in a society? How do social interactions lockdown and testing policies to curb an epidemic? These are some questions that I seek to answer in my research, through the lens of theoretical models and empirical analysis. In this note, I'll discuss my projects and how they try to answer the above questions. An accompanying document provides a brief overview of some ideas in the pipeline and potential for grant applications.

With many countries still struggling to cope with the deadly *covid-19* pandemic, economists have made a concerted effort over the last year to lend their insights into epidemiological models. While this amalgamation has provided novel ways to understand epidemic mitigation policies and the roles of social distancing, most of the growing literature has abstracted away from studying testing and, in general, strategic considerations.[1] Our paper titled **"Behavioural epidemiology: An economic model to evaluate optimal policy in the midst of a pandemic"** incorporates far-sighted strategic agents and government into a rich SIR model. We provide a tractable way to analyse the informational complications that arise from introducing testing-tracing capabilities of the government. This provides a significant methodological improvement over the existing literature, and provides a benchmark for a plethora of questions that are yet to be answered regarding the role of testing-tracing. Using data from US, we are able to compute optimal lockdown and testing policies for the government as well as the social distancing policies for agents. Owing to the abstract nature of our setup, we are able to conduct a multitude of policy analysis - including the "Swedish Experiment", where the government never locks down the economy and rather depends on herd immunity to mitigate the epidemic.

Keeping in line with the nature of the *covid-19* pandemic, we augment a standard SIR model with additional hospitalisation and death states.[2] There is a unit mass of agents connected in a multiplex graph - one type of link denotes a *social activity* link, while the other type is an *economic activity* link. In every time period and in each link, an agent is randomly matched to another agent in the society. A susceptible agent becomes infected only if he is matched with a sick agent in either link. Infected agents either recover or develops severe symptoms and transits into the hospitalised state. The latter may then recover with time or die. Social distancing limits the rate of matching in the social activity links. Lockdown plays a corresponding role along economic activity links, leading to reduced output produced in the economy. Moreover, in line with the plethora of asymptomatic infections, we assume that agents do not distinguish between the susceptible, infected, or recovered phases. The government can implement *testing and tracing* to reveal the health status of individuals. This forces infected agents to go into *quarantine* and produce no output (*i.e. all their links are broken*). In every period, the agents and government strategically choose their social distancing and lockdown levels respectively. New matches are then created, followed by state transitions in the economy. Testing is done by the end of the period and it is revealed whether a vaccine has arrived. The latter indicates the end of the pandemic and arrives randomly in any period at a positive rate. We solve this model for infinitely-lived far-sighted agents

[1] A sizeable literature studies the government's optimal lockdown policies by imposing a social planner's problem on a SIR model (*e.g. Argente et al (2020)*). On the contrary, there are papers that squarely focus agents' social distancing policies (*see e.g., the laissez faire model of Farboodi et al (2020)*).

[2] A standard SIR model consists of three states - susceptible (S), infected (I), and recovered (R).

and government and estimate parameters using US data. In the optimal policy, we show how the best responses of the two parties determine the equilibrium dynamics of the epidemic. In particular, we highlight the substitutable nature of social distancing and show how testing confounds the traditional *reproductive numbers* that are reported in the literature. We also compute a Pareto frontier that guides governments to quantify the tradeoff between economic loss and total deaths in the economy.

A month before the Indian general elections in 2019, the Congress party announced the NYAY (universal basic income) scheme that guarantees a lump-sum amount of INR 72,000 per annum to poor households. The party, to counter the incumbent BJP juggernaut, ran an expensive but poorly targeted awareness campaign - it turned out that the largest beneficiaries about the project (the poorest households) were among the least aware of the project (link). Such dismal targeting ultimately contributed to the Congress party's crushing defeat at the ballots a month later. My paper titled **"Who to share information with? A model of persuasion in social networks"** sheds light on how institutions can further their agenda by utilising social networks to efficiently target information. The concept of leveraging social networks is not new - businesses have used word-of-mouth processes to spread awareness of their trade since the 15th century at least.[3] With a lack of proper academic treatment, however, most of these techniques relied on some heuristic rules. This often resulted in very expensive and inefficient campaigns, as the Congress party learnt to its own detriment. Academic interest in networks and word-of-mouth gained interest with the proliferation of the digital age, combined with the increasing ability to analyse extremely large and sparse datasets. How could the Congress party improve its targeting policy? My theoretical results provide exactly such a guideline - I show that the the optimal "seeding" of information in a social network is a function jointly determined by the accuracy of information sent and properties of the underlying social network.

My simple theoretical model encompasses elements of bayesian persuasion, information transmission, and network diffusion to study the information targeting problem. The model consists of an institution and a set of voters connected in a social network. The latter may have biases for or against the institution. There is a state of the world, unknown to either party, which could be either "good" or "bad". Voters want to vote for the institution if and only if the state is "good", giving them an incentive to learn the state. The institution aims to persuade the voters to vote in its favour by providing some information about the state. However, it can only provide this information to a subset of voters, necessitating him to choose among the possible subset of voters. The design of information, combined with the choice of voters who first receive information, together determines the "seeding" strategy for the institution and sets off the diffusion process. The set of voters who initially receive information can decide whether to communicate this information with their neighbours in the social network, thereby propagating the diffusion across the network topology. Following a finite round of such communications, voters sincerely vote for or against the institution. In this context, I characterise the equilibrium information sharing networks and show that the optimal "seeding" strategy for the institution reflects a fundamental trade-off: *As the information sent by the institution becomes more accurate, it's ability to persuade voters about the "good" state is lowered and the chances that voters will vote in favour the institution is diminished. On the contrary, more accuracy incentivises communication by reducing uncertainty, leading to larger spread in the network. Larger spread, in turn, increases the chances of voters acting upon the information received to vote in favour of the institution.* In stark contrast to the existing literature, where targeting strategies are typically determined by some exogenous centrality of the nodes, the notion of "centrality" in my paper is endogenously determined by the accuracy of information and communication strategies. Among other things, this reflects the extent to which ignoring strategic incentives may lead to misleading targeting

[3] In another related example, Padget and Ansell (1993) describe how the Medici family in Florence used marital alliances to consolidate itself at the centre of the Florentine political network. This allowed them to remain *de-facto* rulers of Florence for more than three centuries.

policies. The abstract nature of the model lends itself to a variety of applications other than the political one that I alluded to. For instance, one can easily reinterpret the institution as a *seller* trying to release a trial version of its product. The voters are then *buyers* who decide whether to buy or not depending on what recommendations they receive from their neighbours. Some have argued, following Akbarpour et al (2020), that leveraging network data is very expensive, and one can perform almost as well through well-designed random seeding of information. Nevertheless social network data is increasingly available, with social media sites like Facebook and Twitter selling network data in data markets.[4] Strategic incentives also make random seeding much more complicated, reducing much of the benefits from not gathering network data.

In a somewhat distinct flavour, a nascent project titled **"Game theoretic model of network security"** studies how security technologies can be designed in a network to intercept harmful objects. Consider a potential terrorist threat - a terrorist needs to choose a city to attack and needs to send an explosive along one of the several paths that lead to the city. Along each path, there could be security checks who can conduct costly checks and intercept the explosive. If intercepted, the city is saved, and the terrorist loses. If the explosive reaches the chosen attack location undetected, the city is destroyed and the terrorist wins. What is the optimal attack location and paths chosen by the terrorist? How can security points minimise the chances of the city being destroyed when acting independently? Is there any way to co-ordinate these checks across complex networks? These are some of the questions that I seek to answer in this paper. I frame the above problem in the context of a network. The terrorist is a fixed node in the network (say, with label T) while the rest of the nodes are possible attack locations. The terrorist chooses an attack location A and a path between nodes T and A to send the explosive. Each node simultaneously invests in a security technology that detects the explosive with some probability. I characterise the Nash equilibrium of this game and show that the terrorist always chooses a mixed strategy in equilibrium. I also characterise the optimal paths as a function of the network, and show that locations that are attacked with 0 probability never invests in any security technology. I am currently working on a mechanism design setup, where a designer can design the network optimally and/or co-ordinate among the nodes to minimise the chances of an attack being successful.

[4] As a simple illustration, many food-delivery firms use data from referral coupons like *"get a $5 discount if you get 5 of your friends to sign up"* to learn about the underlying social networks in the area.