Essays in Decision Making and Economic Networks

Ruhi Sonal
Entry no. 2015HUZ8132
Thesis advisor: Prof. Saptarshi Mukherjee
Department of Humanities and Social Sciences, IIT Delhi

June 2020

Abstract

Several studies have explored the decision making behavior of individuals. Individuals often do not choose an alternative or take an action that is considered the "best" among the available options. The explanations for this phenomenon vary: cognitive constraints, the specifications of the objective function, etc. I study individual decision making in two distinct contexts:

First, I consider a representative decision maker who is *attention constrained*. Imperfect attention (or inattention) results in randomness (or stochasticity, as used interchangeably in this thesis) in the observed choice behavior. There is a growing literature on stochastic choice with attention constrained decision makers but the source of such inattention remains underexplored. In this thesis, I model the source of inattention. A decision maker's attention varies due to the manner in which products are presented. For example: packaging, advertisement, placement of products on different shelves and aisles in a supermarket etc. I characterize a class of stochastic choice rules that the decision maker follows if and only if the observed choice data satisfies a set of axioms. I also model stochastic choice when the products appear in a specific structure- the "ordered tree". This structure is applicable to supermarkets where products may be placed on shelves that differ in terms of their location in the shop. I find the necessary and sufficient conditions on the probabilities with which different locations in a supermarket attract the decision makers' attention such that the observed choice behavior respects the binary relation in the proposed choice rule, irrespective of the

arrangement of the products. In this thesis, chapters 2 and 3 develop the above models and provide the main results.

Second, I consider individuals who strategically decide to connect with others, thereby forming social networks. Individuals form social or professional networks for several reasons such as access to employment opportunities, sharing and disseminating ideas, trade and investment etc. The scope of the problem and the approach in this thesis includes extending and applying results in the existing literature on infinite horizon games in the context of network formation. I model the formation of networks in a game-theoretic framework, and adapt the equilibrium concepts of perfect equilibrium and Bayes' Nash equilibrium to the relevant settings. Specifically, I consider the situation in which individuals positively value the number of connections (or "followers") that they have. Examples of networks formed on online social media platforms such as LinkedIn, Twitter or Instagram are within the ambit of the proposed model. Each individual has a "type" (for example, educational qualifications, skill levels, etc.) perceived by the others. I assume that the types may take any value in the continuum $[0, 1]$. The decision to form a connection is strategic since individuals also want to attract connections. An individual may decide to connect with an individual whose type is lower than another individual in order to prevent others from connecting with the individuals with high type in future. An individual with a relatively higher type may therefore end up with fewer connections than someone with a lower type. The network structure that emerges as a result of a sequence of individual decisions has important implications such as transmission of information. I model the choice of individuals to connect with others in two settings: (i) complete information; and (ii) asymmetric information. I find the conditions that suffice for the relevant equilibrium notion in an infinite horizon game in (i). I explore interesting behavioral phenomena such as "herding" i.e., when individuals imitate others' actions and connect to the same individual. I show that under certain conditions individuals strategically optimizing their own utility display herd behavior i.e., they imitate actions of others even if it requires them to connect with individuals with lower type instead of higher type in both (i) and (ii). In (ii), I also show that in the presence of asymmetric information, in specific equilibria, individuals will truthfully signal their type. Chapters 4 and 5 provide formal models in the two settings outlined above and provide the main results.

The first chapter in the thesis introduces the two broad research questions outlined above. Here is a detailed description of the rest of the chapters in the thesis:

Chapter 2: I model stochastic choice with framing effects. An individual decision maker's observed choices are random due to imperfect attention. Random choice has been previously modeled in the literature in several papers such as Luce (1959), Block et al. (1959), Barberà and Pattanaik (2010), Manzini and Mariotti (2014), Manzini and Mariotti (2015), Fudenberg et al. (2015), Yildiz (2016), Ahn et al. (2017), Caplin and Martin (2018), Manzini and Mariotti (2018) and Cattaneo et al. (2019). The phenomena of imperfect attention has also been previously modeled as the reason for the observed stochasticity in Manzini and Mariotti (2014). A *frame* is the manner in which an alternative is presented to the decision maker. It may take various forms such as positioning of an item in the shelf of a supermarket, endorsement of a product by a celebrity, packaging an item in a particular manner etc. The role of frames in attracting the decision maker's attention and thereby influencing the choice probabilities remains an open question. In this chapter, stochasticity in choice is explained by the frames with which the alternatives appear. For example, if a product is kept on a shelf that is at the eye-level of the decision maker, then it may attract more attention than products kept at the bottom-most shelf in a shop [1].

In this model, the decision maker encounters each alternative (say, x) with an associated frame (say, i). The tuple (x, i) is called a "product". I characterize a class of stochastic choice rules called the *frame-based stochastic choice rule* using three axioms: *invariance of singletons*, *dominance* and *stochastic path independence*. According to this rule, there exists a complete binary relation over the set of alternatives and an attention function that assigns a probability to every frame such that for any set of products G, the choice probability of (x, i) in G is the probability that attention is drawn by frame i and not by frames attached to those alternatives in G that beat x according to the binary relation. The binary relation and the attention function in the rule are identifiable. The attention parameter is interpreted as the probability with which a particular frame draws the decision maker's attention. An important behavioural aspect of the rule is as follows: the role of a frame is limited to drawing the decision maker's attention; the frame associated with an alternative does not influence the consumer's taste. This interpretation is the same as in Salant and Rubinstein (2008), which models deterministic choice in the presence of frames. In this framework, the decision-maker may choose a less preferred alternative with higher probability even when a better alternative is available. The three axioms are independence requirements on

[1] Gidlöf et al. (2017) and Seva et al. (2011) provide experimental and empirical evidence

the choice probabilities and are shown to be necessary and sufficient for the rule.

To the best of my knowledge this is the first attempt towards developing a general framework for the analysis of framing effects in a stochastic setting. The attention probability in this model is a function of the frame, but is not required to follow a specific functional form. It is independent of the decision maker's preferences and also of the characteristics of the alternatives. The rule characterized demonstrates the effects of frames in drawing a consumer's attention to a product. This framework extends to settings where the frames are positions in a list (Rubinstein and Salant (2006)) or ordered trees (Mukherjee (2014)).

Chapter 3: In this chapter I extend the model developed in chapter 2 to the setting of decision making from an "ordered tree." An example of the structure of an *ordered tree*[2] is the organisation of products in a supermarket.

Consider a supermarket that has four shelves where the products can be placed. One shelf is located on the left of the entrance, while three are on the right. Suppose that the product x is placed on the shelf on the left, while y, z, and w are kept on the shelf on the right. Note that a supermarket can be denoted as an ordered tree if there is a unique path leading to each product. The structure of the tree is assumed as fixed, while products may be arranged in different ways. In the model, products are placed only at the terminal nodes. I characterize a stochastic choice rule from an ordered tree, and find the conditions under which the choice data respects the binary relation in the rule.

In the literature, Mukherjee (2014) models deterministic choice from an ordered tree. To the best of my knowledge, stochastic choice in this setting has not been explored previously.

A product is assigned to each terminal node of an ordered tree and the decision maker's choice from this assigned tree is stochastic. The class of rules characterized in this chapter is called the *attention based rule.* The three axioms introduced in the previous chapter are adapted to the setting of ordered trees. These axioms are necessary and sufficient for choice behavior to follow the attention based rule.

The rule computes the probability with which a product is chosen from an assigned tree as follows: there exists an attention probability associated

[2]Henceforth the term 'tree' is used to refer to an 'ordered tree.'

with each path that leads to a terminal node. The choice probability of a product is the probability that the path leading to the product draws the decision maker's attention and the probability that attention is not drawn by those paths that lead to "better" products according to the binary relation.

Similar to the frame-based stochastic choice rule introduced in chapter 2, notice that a decision maker may choose a product with lower probability even if it is better than another product due to the positions of the products according to the attention based rule. In this context, I introduce the following notion of "consistency": a random choice rule from a tree is consistent if for any assigned tree, if x 'beats' y then x is chosen with higher probability than y. If a given supermarket satisfies this property, then the decision maker will choose the preferred product with the highest probability irrespective of where it is kept. I show that a subclass of the attention based rules is consistent when the attention parameters follow a specific structure.

Chapter 4: In the fourth chapter, I consider a class of games with an infinite time horizon i.e., there are countably infinite stages. In each stage, one agent enters the game and each agent has a "type" which is common knowledge. The type of an individual affects the value of a link with her for other individuals. Consider the example of "links" between people on social media platforms such as LinkedIn. Individuals join the platform in different time periods rather than simultaneously. Further, when an individual joins the platform she chooses whom to connect with from the set of existing members of the social network. Another example of this setting are professional networks - consider a lawyer or a doctor who has just earned her degree seeking an internship with another lawyer (or doctor). She can choose only one from a set of available internship opportunities, each with a lawyer whose type may differ. Once she has obtained an internship, she may in future provide internships to lawyers who are junior to her.

The choice of connecting to an individual is strategic, since one individual's choice may affect the choice of individuals who enter the game after her, and thereby the network structure. Since there is complete information, an individual knows how her choice will affect the decisions of others, and will therefore use this information in order to optimize her own payoff. Note that in such a setting, equilibrium cannot be computed using the concept of sub-game perfect Nash equilibrium (SPNE) or the backward induction method since the game is not finite. I model an infinite horizon game in which the outcome is a network. Fudenberg and Levine (1983) introduced a technique for finding the equilibria in such games, which was simplified to an adaptable form by Börgers (1989). I use Börgers (1989) technique to compute the sufficient conditions for "perfect equilibrium" and explore some interesting network structures that occur in equilibrium.

I show that in some classes of equilibria, agents take actions that have behavioral intuitions: for example, in one class of equilibria, each agent imitates the actions of the agent who joined the game immediately before them. In the setting of network formation, such behavior leads to the formation of a "star" network as described by Jackson and Wolinsky (1996). This particular network structure is interesting due to its property of efficiency (Jackson and Wolinsky (1996)). When an agent imitates the action of the previous agent, I call it "herding". I provide the sufficient conditions for herding to occur in equilibria. The insights offered by the model are rich enough to be further explored from different perspectives for example, a mechanism design approach would seek to devise a mechanism to implement a particular network structure. In the framework provided by this chapter, this can be achieved by manipulating the sequence in which the individuals enter the game.

Chapter 5: In chapter 5, I introduce asymmetric information in a setting similar to chapter 4: each individual knows her type, but not the types of the others. For example, online social networking platforms enable individuals to connect with people who may not be known to them. Each individual creates a profile that lists their skills, educational qualifications and details about their work experience (for instance, LinkedIn). All profiles are publicly visible and act as signals. Individuals decide whom to connect with after observing these signals. In the example of lawyers seeking internships with other lawyers outlined in the summary of chapter 4, the role of asymmetric information is clear - the quality of the lawyers are not observable, but their performance in law school or work experience signals their type.

Notice that when information is asymmetric, the choice of the signal by each individual is strategic, as existing individuals in the network and subsequent entrants decide whom to connect with on the basis of the signals that they observe. The solution concept used in this setting is Bayes' Nash equilibrium and I characterize the class of equilibria in which individuals follow the strategy of herding. I also characterize a class of equilibrium in which herding occurs after some time periods. I show that truthful signals are chosen in the "herding equilibrium" (i.e., an equilibrium in which all individuals except one have a direct link with the same individual). The model shows that the conditions required for individuals to display herd behavior become weaker as more and more people enter the network. In situations where the dissemination of information relies on networks, such network structures are important. The results in this chapter can be adapted to design sequences in which individuals enter a network in order to implement a desired network structure in the presence of asymmetric information.

This thesis is an attempt to deepen the understanding of individual decision making and to provide a framework for further research in the two broad areas that I have studied. I hope that this objective is satisfactorily achieved.

References

AHN, D. S., F. ECHENIQUE, K. SAITO, ET AL. (2017): "On path independent stochastic choice." *Theoretical Economics*, 13, 61–85.

BARBERÀ, S. AND P. K. PATTANAIK (2010): "Falmagne and the rationalizability of stochastic choices in terms of random orderings," *Econometrica*, 118, 274–299.

BLOCK, H. D., J. MARSCHAK, ET AL. (1959): "Random orderings and stochastic theories of response," Tech. rep., Cowles Foundation for Research in Economics, Yale University.

BÖRGERS, T. (1989): "Perfect equilibrium histories of finite and infinite horizon games," *Journal of Economic Theory*, 47, 218–227.

CAPLIN, A. AND D. MARTIN (2018): "Framing as information design," *www.martinonline.org.*

CATTANEO, M. D., X. MAZ, Y. MASATLIOGLU, AND E. SULEYMANOV (2019): "A random attention model," *Working paper.*

FUDENBERG, D., R. IIJIMA, AND T. STRZALECKI (2015): "Stochastic choice and revealed perturbed utility," *Econometrica*, 83, 2371–2409.

FUDENBERG, D. AND J. LEVINE (1983): "Sub-game perfect equilibria of finite and infinite horizon games," *Journal of Economic Theory*, 31, 251–268.

Gidlöf, K., A. Anikin, M. Lingonblad, and A. Wallin (2017): "Looking is buying. How visual attention and choice are affected by consumer preferences and properties of the supermarket shelf," *Appetite*, 116, 29–38.

Jackson, M. O. and A. Wolinsky (1996): "A strategic model of social and economic networks," *Journal of Economic Theory*, 71, 44–74.

Luce, R. (1959): *Individual choice behavior: a theoretical analysis*, John Wiley and Sons.

Manzini, P. and M. Mariotti (2014): "Stochastic choice and consideration sets," *Econometrica*, 82, 1153–1176.

——— (2015): "Modelling imperfect attention," *Working paper 744, Queen Mary University, London.*

——— (2018): "Dual random utility maximisation," *Journal of Economic Theory*, 177, 162–182.

Mukherjee, S. (2014): "Choice in ordered-tree-based decision problems," *Social Choice and Welfare*, 43, 471–496.

Rubinstein, A. and Y. Salant (2006): "A model of choice from lists," *Theoretical Economics*, 1, 3–17.

Salant, Y. and A. Rubinstein (2008): "(A, f): Choice with frames," *The Review of Economic Studies*, 75, 1287–1296.

Seva, R. R., K. Go, K. Garcia, and W. Grindulo (2011): "Predictive model of attention in viewing selected grocery products," *DLSU Business and Economics Review*, 21, 97–110.

Yildiz, K. (2016): "List-rationalizable choice," *Theoretical Economics*, 11, 587–599.