

BEHAVIORAL INFLUENCE

Christopher P. Chambers
Georgetown University, USA

Tugce Cuhadaroglu
University of St Andrews, UK

Yusufcan Masatlioglu
University of Maryland, USA

Abstract

In the context of stochastic choice, we introduce an individual decision model that admits a cardinal notion of peer influence. The model presumes that individual choice is not only determined by idiosyncratic evaluations of alternatives but also by the influence of the observed behavior of others. We establish that the equilibrium defined by the model is unique, stable, and falsifiable. Moreover, the underlying preferences and influence parameters as well as the structure of the underlying network are uniquely identified from, arguably, limited data. The baseline model includes two individuals with conformity motives. Generalizations to multi-individual settings and negative interactions are also introduced and analyzed. (JEL: D01, D91)

Teaching Slides

A set of Teaching Slides to accompany this article are available online as [Supplementary Data](#).

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E-mail: Christopher.Chambers@georgetown.edu (Chambers); tc48@st-andrews.ac.uk (Cuhadaroglu); yusufcan@umd.edu (Masatlioglu)

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1. Introduction

It is a well-established fact that individual choices are directly influenced by the choices of one's peers.¹ Identification of peer influence out of observable behavior has been a challenging problem for social scientists for decades.² At the heart of this issue lies Manski's reflection problem (Manski 1993): Behavioral similarities among peers can be caused by correlated unobserved or observed characteristics as well as peer influence. Distinguishing between these effects is not straightforward due to the simultaneity in the behavior of interacting individuals. This paper provides a novel approach to the identification of peer influence by focusing on the microfoundations of interaction rather than adopting ex-post estimation techniques. We introduce a simple model of decision-making for interacting individuals that enables inference of underlying unobserved parameters out of observable behavior.

The novelty in our approach lies in the introduction of a new source of variation for social interaction models. Specifically, we vary the set of available options from which individuals choose. Without any variation in the choice set, the reflection problem cannot be solved. However, with minimal variation, such as observations from two choice sets rather than one, it becomes possible to identify the social influence. For instance, consider two friends, Dan and Bob, and their choices on daily exercise routines during a countrywide lockdown due to a pandemic. Under strict government rules, they can choose to either exercise at home or go for a walk outside. Let Dan choose to exercise at home 71% of the time and go for a walk for 29%, whereas these frequencies would be 78% and 22% for Bob, respectively. Reflection problem emerges exactly at this point, where an outside observer cannot tell whether these friends are behaving similarly because they are influencing each other or they indeed have similar preferences (and/or backgrounds); and hence, they would have also behaved the same way without interaction. Without any further information, an outside observer cannot differentiate between these two scenarios. In order to overcome the reflection problem and identify peer effects out of observable behavior, our methodology suggests to exploit the changes in these individuals' behaviors over a new choice set. For instance, when the lockdown is over and the updated government regulations allow also for exercising in the gym. These individuals' behaviors under these two scenarios, that is, (exercise at home and go for a walk) and (exercise at home, go for a walk, and go to gym), are sufficient for our identification strategy to identify the peer effects as

1. There is an abundance of evidence corroborating peer influence in a variety of social contexts: Peer behavior has a significant influence not only on a student's school achievement (Calvo-Armengol, Patacchini, and Zenou 2009), but also on social behaviors such as consumption of recreational activities, drinking, smoking, etc. (Sacerdote 2011). High productivity co-workers are found to increase one's own productivity (Mas and Moretti 2009). Involvement in crime (Glaeser, Sacerdote, and Scheinkman 1996), job search (Topa 2001), adolescent pregnancy (Case and Katz 1991), and college major choice (De Giorgi, Pellizzari, and Redaelli 2010) are other prominent examples in which social interactions are shown to be crucial constituents of individual behavior.

2. See Blume et al. (2011), Bramoullé, Djebbari, and Fortin (2020) for early and recent reviews of literature, respectively.

long as the observed choices are consistent with our model, as we will illustrate after introducing the model briefly.³

Our main contribution is to provide an intuitive and tractable decision model that affords a meaningful and measurable definition of “influence” as derived from choice behavior alone. Our model consists of two essential parameters: an individual preference parameter and an individual influence parameter. The latter captures interdependence of behavior across individuals and can accommodate different values for different peers, enabling heterogeneity of peer effects. The individual preference parameter is more standard. It can be interpreted as the intrinsic utility of the underlying alternatives; the subjective value of the alternatives absent any social effects.⁴ Social influence transpires through the *observed behavior* of the other individual(s), where subjective value of each alternative is adjusted by a weighted version of the observed behavior of others regarding that alternative. As a result of this weighted aggregation process, individual choice behavior reflects the relative utility of each alternative in a given menu altered by social influence. More precisely, the choice frequency of each alternative from a menu is equal to the relative utility of this alternative under social influence, with respect to all other available alternatives.

Our identification strategy exploits the change in choice frequencies when a new alternative is introduced in order to pin down the peer influence and the underlying preferences. Going back to the example of exercise behavior, let us observe that once the government regulations allow for going to the gym, Dan and Bob’s behaviors change as follows: Dan exercises at home 60% of the time, goes for a walk for 26%, and goes to the gym for 14%, whereas these frequencies are 70%, 19%, and 11% for Bob, respectively. This pair of behaviors is consistent with our model (as described in Section 2.3), hence, we can reveal the underlying preferences and the interaction parameters uniquely, overcoming the reflection problem. Interestingly, our identification strategy (as described in Section 2.2) implies that although Dan and Bob’s choice frequencies are aligned over exercise options, their idiosyncratic preferences are not aligned. For Bob, indeed, the intrinsic utility of home exercise is the highest and going for a walk is the lowest, whereas for Dan, the exact opposite holds. However, Bob’s behavior has a great influence on Dan. To be precise, conformity with Bob’s behavior is five times more important to Dan than his own subjective evaluation, whereas for Bob, his own evaluation and Dan’s behavior are equivalently important.⁵ Thus, thanks to our

3. Although variation of choice sets is a standard tool for revelation in choice theory, it has not been commonly adopted outside this literature. One exception would be the identification of differentiated product models in IO as in Berry, Levinsohn, and Pakes (2004).

4. In social interactions literature, the non-influence parameters that affect individual behavior are defined via types of variables such as predetermined social factors, including gender, age, race, etc. Our model abstracts away from these effects, classifying them under the individual preference parameter.

5. Section 2.1 introduces our model formally, but as described above two critical parameters constitute the primitives. In this example, the preference parameters, the intrinsic utility weights of exercise at home, go for a walk, go to gym, for Dan and Bob are 0.1, 0.3, 0.6 and 0.8, 0.08, 0.12, respectively, with corresponding interaction parameters 5 and 1.

identification strategy, we can deduce that strong conformity motives have resulted in the observed behavior.

Our model is a stochastic choice model that assumes consistent behavior across all budget sets. Critically, this menu variability grants us unique identification (or point identification, as coined in the econometrics literature). Moreover, our identification strategy does not suffer from a common handicap of identification in revealed preference or decision-theoretic models: arguably unrealistic data requirements. Many choice theoretic models require a rich dataset, typically individual choices from all menus, for identification purposes.⁶ As we show in Section 2.2, observations from only two menus are sufficient for unique identification for our baseline model, involving two individuals. For identification of influence networks involving more than two individuals, observations from two menus can still be sufficient as long as there are sufficiently many alternatives in the menus. We elaborate more on this in Section 3.

We establish in Section 2.3 that our model is falsifiable by providing its empirical content in terms of choice. Three behavioral properties are sufficient to characterize the model. All of these properties are built around a cross-elasticity type parameter that evaluates the relative rate of change in the individual choice frequency of an alternative as a response to a comparative change in the behavior of the other individual(s). In contrast to standard models of individual choice, this influence parameter is derived from the choice behaviors of *all* of the individuals jointly, as opposed to the behavior of only one individual. Hence, these characterizing properties are entirely novel.

The parameters of our model define an “equilibrium”, where the choice behavior of each individual is a function of idiosyncratic utility and influence parameters, as well as the behavior of the other individual(s). Unlike many other discrete choice models (Brock and Durlauf 2001; Blume et al. 2011), the equilibrium defined by our model is unique. Moreover, it is also stable in the sense that a dynamic adjustment procedure always tends to this unique equilibrium. In other words, if we believe that each individual aggregates behaviorally according to our procedure, we should expect their behavior to conform to our model in the long run. There are two critical implications of this result. The first implication is more practical: If one individual mistakenly chooses, or one of them misobserves the other’s choices at some period in time, then their behavior will still revert to the predictions of our model in the long run. Second and more importantly, identification of the underlying parameters from dynamic data is also possible. Then, in the absence of equilibrium choice behavior, we can use a similar identification strategy over consecutive choice data. Section 2.4 elaborates on this.

Our baseline model involves two individuals with conformity motives, as in the example above. An action’s choice probability increases as the action is chosen more frequently by one’s peers. However, our model easily adapts to more individuals and accommodates other types of interaction. We present two simple extensions. The first

6. For a recent exception to this common trend as well as a discussion on the topic, see Dardanoni et al. (2020).

incorporates multi-individual interaction, where individuals have different degrees of influence on the behaviors of their peers; and the second is “negative” influence, where the choice probability decreases as it is chosen more frequently by some peers.

We provide three distinct and well-known social influence settings, where the behavior produced by our model can be reproduced under certain assumptions. We refer to these as “foundational justifications” for our model, since each of them can be seen as an economic mechanism underlying our model of influence. The first of those incorporates strategic interactions, introducing a simultaneous game setting whose Quantal Response Equilibrium happens to coincide with our model, whereas the second one is utility maximization in a discrete choice setting with peer effects. The last mechanism is a basic naive learning set up as in DeGroot (1974). All of these models are distinguished from our model as we use menu variability in our setting.

The organization of this paper is as follows. The next subsection is devoted to literature review. Section 2 presents a detailed analysis of the baseline model with two individuals with conformity motives, including identification, falsifiability, and stability results, as well as the foundational justifications. Section 3 introduces the generalization to multi-individual settings. Section 4 concludes. All proofs are left to an appendix. The incorporation of negative influence to dual and multi-individual models is left to the Online Appendix.

Related Literature. Economics research on the identification of social interactions has mainly utilized econometric tools and techniques. Most of these studies employ *linear social interaction models* (Manski 1993; Blume et al. 2011, 2015; Jackson 2011), where the individual utility of an action is defined as a linear additive function with two components: an individual private utility and a social utility. Blume et al. (2015) provide micro-foundations to these linear interaction models by showing that, under certain parametric assumptions, they can be reproduced as the Bayesian–Nash equilibrium of an incomplete information game where individuals choose an action to maximize their expected utility given their type and the public types of others.⁷ Calvo-Armengol, Patacchini, and Zenou (2009) investigate the effects of the structure of social networks and show that an underlying peer effects game rationalizes individual outcomes, where at the Nash equilibrium each outcome is proportional to the centrality of the individual within the network.

Linear social interaction models are defined for continuous choice variables. An alternative to this has been developed by incorporating the linear additive utility function with interaction effects into a discrete choice setting (Blume 1993; Brock and Durlauf 2001, 2006). Binary or multinomial discrete choice models with social interactions make use of random field models to study the equilibrium. Three critical assumptions ensure the tractability of the model. First, the assumption of constant strategic complementarity: The cross-partial of social utility is a positive constant that is the same for all individuals. Second, rational expectations: The expected

7. For identification strategies without parametric assumptions, see Brock and Durlauf (2007).

average behavior is simply the objective average behavior. Finally, the error terms follow a relevant extreme value distribution. These assumptions are sufficient to produce individual choice outcomes that are consistent with logistic choice with multiple equilibria. The majority of these papers assume large populations in order to justify the assumption that each individual ignores the effect of their own choice on the average choice of the society. An exception to this is Soetevent and Kooreman (2007), where they consider interaction in small groups in which the choices of other individuals are fully observable. Thus, the choice of an individual directly depends on the observed behavior of the others. Our model also uses this intuition. Indeed, under certain assumptions, the behavior produced by a multinomial discrete choice model with social interactions coincides with the behavior produced by our baseline model. This requires a different error distribution than the one commonly assumed for those works. We clarify this connection in Section 2.5.

In this strand of literature, social interactions have typically been taken to be generated by group specific averages. Incorporating network theory into the study of the identification of social interactions has enabled a much richer analysis of the microstructure of interactions. Early works on this assumed a *known* network structure, based on common observables or self-reported, elicited data (Bramoullé, Djebbari, and Fortin 2009; De Giorgi, Pellizzari, and Redaelli 2010; Lee, Liu, and Lin 2010). However, both of these methods bear shortcomings for econometric methods or practical reasons related to collecting data (De Paula 2017). A first improvement on this was suggested by Blume et al. (2015) by assuming only partial information on the structure of the underlying network. De Paula, Rasul, and Souza (2019) advance on this by assuming no a priori information on the network structure and provide sufficient conditions for full identification of social interactions with panel data. Our paper is complementary to this literature since our general model also encompasses an influence network, where the structure of the relations does not need to be known a priori. Instead, it is fully revealed by the behaviors thanks to our identification strategy.

It is important to note that many theoretical models for identification of peer influence are restricted by strategic complementarity (Blume 1993; Brock and Durlauf 2001, 2006; Blume et al. 2011):⁸ Individual utility over an action increases with the number of peers taking the action, explaining mostly conformity-type behavior. However, empirical evidence points out to negative interactions as well. For instance, Glaeser, Sacerdote, and Scheinkman (1996) suggest the existence of negative interactions among criminals due to competition for resources. Bhatia and Wang (2011) study peer effects in physicians' prescription behaviors and find a significantly negative effect on each other's prescription behaviors, partly explained by observational learning and congestion effects. Foster and Rosenzweig (1995) find evidence of a negative relation between the experimental technology adoption rates of farmers and

8. Exemptions to this include structural models to identification such as Bramoullé, Djebbari, and Fortin (2009), Cohen-Cole, Liu, and Zenou (2018). Bramoullé (2007) studies the effect of the structure of the network on equilibrium behavior for games of anti-coordination, where there are incentives to anti-coordinate.

their neighbors. As we show in an extension in Online Appendix D, our model can accommodate certain types of negative interactions.

The use of choice theoretic tools to study social interactions is quite recent. As far as we know, the first choice-theoretic work investigating influence across individuals is Cuhadaroglu (2017). This work introduces a deterministic model of two stage optimization where the first stage involves the maximization of own preferences (transitive but not necessarily complete), and the second stage accommodates social influence to further refine first stage outcomes. Recently, two contemporaneous studies incorporate choice theoretic analysis to identification of peer effects. Borah and Kops (2018) and Kashaev and Lazzati (2021) both propose decision procedures in group settings that make use of “a consideration set” approach. Borah and Kops (2018) propose a two stage mechanism, where the first stage is devoted to the formation of consideration sets with those alternatives that are chosen sufficiently enough by the members of peers, and the second stage is devoted to preference maximization. Kashaev and Lazzati (2021) incorporate random consideration sets into the dynamic model of social interactions of Blume (1993). The main difference of our work from these models is about the channel through which others’ behavior influences the individual. Our model presumes that social influence alters one’s behavior via preferences, whereas those two papers assume a limitation of the choice set due to social influence.⁹

Fershtman and Segal (2018) also consider a social interaction set up, where individual behavior not only depends on one’s own preferences but also on the behavior of other agents in an expected utility framework. A social influence function converts the private utility of the agent and the observable utilities of everyone else to an observable utility for the agent. They study certain properties of social influence functions and their implications for the equilibrium without proposing an explicit behavioral model.

Finally, our work is related to the literature discussing the revealed preference implications of solution concepts in games; for example, Sprumont (2000), Lee (2012). One interpretation of the mathematics of our model is to formalize, for each choice set, a game and a solution concept. Thus, our model provides observable predictions of our concept as strategy sets vary. The aforementioned papers also study the predictions of game theory as strategy sets vary. In a similar fashion, our work is also linked to the literature on estimation and inference in discrete games, with the main difference being that, rather than relying on parametric or structural estimation techniques, our main tool of inference is revealed preference. For early works on estimation in discrete games see Bresnahan and Reiss (1991), Kooreman (1994); for inference in large discrete games

9. Many findings from social psychology or experimental economics literatures support the notion that social influence alters one’s preferences. For instance, Kremer and Levy (2008) show that alcohol consumption by one roommate is more likely to influence the alcohol consumption of another roommate via a preference change rather than a modification of the choice set. According to the notion of (mis)identification in social psychology, when some alternatives become identified with certain identities, they become more likely to be preferred by aspiring individuals, whereas despising individuals avoid them in order not to be misidentified (Berger 2016).

see Menzel (2016); and for non-parametric estimation in non-cooperative games see Haile and Tamer (2003).

2. Behavioral Influence

2.1. The Model

Let X be a finite set of alternatives with $|X| > 2$. A *stochastic choice rule* is a map $p : 2^X \setminus \{\emptyset\} \rightarrow \cup_{S \subseteq X} \Delta_{++}(S)$ such that for all $S \subseteq X$, $p(S) \in \Delta_{++}(S)$.¹⁰

We propose a simple model of influence. There are two individuals, 1 and 2. Each individual is influenced by the choices of the other individual. The observable behavior is a pair of stochastic choice rules (p_1, p_2) , where p_i stands for individual i 's choices. We use the notation $i, j \in \{1, 2\}$ with $i \neq j$ for the individuals in general. Then, $p_i(x, S)$ stands for the probability of individual i choosing alternative x from S , certainly with $\sum_{x \in S} p_i(x, S) = 1$.

The primitives of our setting are idiosyncratic weights and influence parameters. Let $w_i \in \Delta_{++}(X)$, so that $w_i(x)$ measures the idiosyncratic weight of the available alternatives for individual i . These can be interpreted as intrinsic utilities of the alternatives absent any social influence effects as in the Luce model.¹¹ We postulate that the choice behavior of individual j regarding an alternative $x \in S$ directly influences individual i 's evaluation of that alternative for the same choice set. Specifically, we assume the utility of agent i from choosing alternative x from budget S is given by

$$w_i(x) + \alpha_i p_j(x, S),$$

where α_i measures the degree of influence of j on i . For the baseline model, we assume that $\alpha_i \geq 0$, hence, α_i acts as a conformity parameter. The higher the probability that j chooses x from S , the higher is i 's evaluation of x in S . The value of x is influenced by the choice probability of others in a linear fashion. Hence, our formulation is in line with the classical linear interaction models such as Manski (1993), Blume et al. (2011, 2015). The choice probabilities are given by the normalized utility values as in the Luce model. Formally,

DEFINITION 1. (p_1, p_2) has a dual interaction representation if there exist $w_1, w_2 \in \Delta_{++}$ and $\alpha_1, \alpha_2 \in \mathfrak{R}^+$ such that

$$p_i(x, S) = \frac{w_i(x) + \alpha_i p_j(x, S)}{\sum_{y \in S} [w_i(y) + \alpha_i p_j(y, S)]} \tag{1}$$

for all $x \in S, S \in 2^X \setminus \emptyset$ and $i, j \in \{1, 2\}$ with $j \neq i$.

10. The notation Δ_{++} refers to the set of probability distributions with full support. We denote $\sum_{x \in S} f(x)$ by $f(S)$ for any function f on X .

11. A stochastic choice rule p has a Luce representation (Luce 1959), if there exists a weight distribution $w \in \Delta_{++}(X)$ such that $p(x, S) = w(x) / \sum_{y \in S} w(y)$ for all $x \in S, S \in 2^X \setminus \emptyset$. This ratio of relative weights is known as the "Luce ratio."

When (p_1, p_2) has a dual interaction representation with parameters $(w_1, w_2, \alpha_1, \alpha_2)$, we say that $(w_1, w_2, \alpha_1, \alpha_2)$ represent (p_1, p_2) .

Dual interaction model defines an equilibrium, where the stochastic choice behavior of the agents ends up being contingent on each other in a particular way.¹² Different cognitive and/or interactive mechanisms may lead to the equilibrium granted by this model. For now, we abstract away from these underlying processes and instead focus on identification and characterization.¹³

In our model, each p_i is only defined implicitly by the procedure in equation (1). p_2 needs to be known in order to determine p_1 and vice versa. However, given $(w_1, w_2, \alpha_1, \alpha_2)$, we can obtain an explicit representation by solving the system of simultaneous equations, arriving at

$$p_i(x, S) \equiv \lambda_i(S) \frac{w_i(x)}{\sum_{x \in S} w_i(x)} + (1 - \lambda_i(S)) \frac{w_j(x)}{\sum_{x \in S} w_j(x)} \quad (2)$$

for $\lambda_i(S) \in (0, 1)$ defined as

$$\lambda_i(S) = \frac{w_i(S)[w_j(S) + \alpha_j]}{w_i(S)w_j(S) + \alpha_i w_j(S) + \alpha_j w_i(S)},$$

where $w_i(S)$ stands for $\sum_{x \in S} w_i(x)$. Equation (2) helps to explain why we think of α_i as a measure of influence. The stochastic choice of i from choice set S is, geometrically, a convex combination of i 's Luce choices and j 's Luce choices. As α_i increases, this combination tends to be closer to j 's Luce choices. In other words, the more the peer influence is, the higher is the weight attached to the peer's Luce ratio. In the extreme case, when $\alpha_i = 0$, $\lambda_i(S)$ is equal to 1, independent of the budget set, and the model boils down to the standard Luce model.¹⁴ In general, each p_i can be expressed as a linear combination of the Luce ratios, where, crucially, the weights in the combination depend on S . Observe that this is "as if" each individual knows exactly not only her own intrinsic utilities but also those of the other individual, which are not necessarily observable. Notice that in our original formulation, each individual

12. It is also possible to think of individuals as if adjusting their behavior according to their *beliefs* about the behavior of their peer, rather than the behavior itself. Under an assumption of rational expectations, as it is common in social interactions literature (Blume et al. 2011), the beliefs happen to coincide with actual behavior. This interpretation is entirely in line with our model. However, since our main goal is to focus on the identification of underlying unobservable parameters out of the observable behavior, we choose not to include this additional dimension.

13. Section 2.5 introduces several prominent examples to these underlying mechanisms.

14. It is worth noting that p_i consistent with dual interaction model does not satisfy IIA, the characterizing property of the Luce model, $(p_i(x, S)/p_i(y, S) = p_i(x, T)/p_i(y, T))$ for all S, T and $x, y \in (S \cap T)$ in general; it only does so when $\alpha_i = 0$ or $\alpha_i \rightarrow \infty$. In the former, there is no influence, hence, i behaves according to w_i , whereas in the latter, i fully mimics j . For an example to the violation of IIA by the dual interaction model, see the example given in the introduction

$$\frac{p_{\text{Dan}}(\text{home}, \{\text{home}, \text{walk}\})}{p_{\text{Dan}}(\text{walk}, \{\text{home}, \text{walk}\})} = \frac{0.71}{0.29} \neq \frac{0.60}{0.26} = \frac{p_{\text{Dan}}(\text{home}, \{\text{home}, \text{walk}, \text{gym}\})}{p_{\text{Dan}}(\text{walk}, \{\text{home}, \text{walk}, \text{gym}\})}.$$

utilizes each other's observable choice behavior rather than their unobservable Luce weights. We believe influence based on observed behavior rather than an unobserved parameter is behaviorally and procedurally more plausible.¹⁵

Another important implication of this formulation is about uniqueness of the behavior produced, which is not obvious from the equilibrium description of the model. Since (p_1, p_2) can explicitly be expressed as functions of the parameters, for a given $(w_1, w_2, \alpha_1, \alpha_2)$, there is a unique pair (p_1, p_2) consistent with the dual interaction model. In other words, our model corresponds to a unique equilibrium.¹⁶

2.2. Identification

Assume we observe (p_1, p_2) that has a dual interaction representation. How can we identify the underlying preferences and interaction parameters? A powerful feature of our model is that our identification strategy requires observation of behavior from only two menus: The universal set X and any menu S that has at least two distinct alternatives, say x and y . To see how, first define for each $i = 1, 2$, for any pair (x, S) with $x \in S$, $d_i : (x, S) \mapsto \Re$, by

$$d_i(x, S) := p_i(x, S) - p_i(x, X).$$

The quantity $d_i(x, S)$ is simply the change in the probability of i 's choosing x as the set X shrinks to S . With $\alpha_i \geq 0$, this change is always non-negative, with the interpretation that in a larger set, there are more alternatives from which to choose.¹⁷ In the dual interaction model, this change is governed by two separate effects. First, there is the individual effect. A larger set includes more alternatives, rendering any given alternative relatively less attractive. Second, there is also a social influence effect imposed by the change of the other individual's choice probability, $d_j(x, S)$. With $\alpha_i > 0$, as the set enlarges, this indirect effect contributes to the loss in choice probability of any given alternative. Let us decompose $d_i(x, S)$ into these two effects explicitly for the model

$$\begin{aligned} d_i(x, S) &= p_i(x, S) - p_i(x, X) \\ &= \frac{1 - w_i(S)}{1 + \alpha_i} p_i(x, S) + \frac{w_i(S) + \alpha_i}{1 + \alpha_i} p_i(x, S) - \frac{1 + \alpha_i}{1 + \alpha_i} p_i(x, X) \end{aligned}$$

15. See Section 4 for further discussion on an alternative model that refers to a convex combination of Luce choices with set independent weights.

16. Let us also finally note that although we restrict our attention to strictly positive stochastic choice rules (hence, considered $w_i(\cdot) \in (0, 1)$), it is possible to extend the model to allow $w_i(\cdot) \in [0, 1]$. In this case two additional properties dealing with 0 probabilities are required for characterization of the model. Although this is a rather straightforward extension, the proof becomes tedious; hence, we choose the restricted setting. The proof is available upon request.

17. Indeed, this refers to the well-known regularity property (Block and Marschak 1960).

$$\begin{aligned}
 &= \frac{1 - w_i(S)}{1 + \alpha_i} p_i(x, S) + \frac{w_i(x) + \alpha_i p_j(x, S)}{1 + \alpha_i} - \frac{w_i(x) + \alpha_i p_j(x, X)}{1 + \alpha_i} \\
 &= \underbrace{\frac{1 - w_i(S)}{1 + \alpha_i} p_i(x, S)}_{\text{individual}} + \underbrace{\frac{\alpha_i}{1 + \alpha_i} d_j(x, S)}_{\text{social influence}},
 \end{aligned}$$

where the $p_i(\cdot)$ s in the second and third components in the second line are replaced with the corresponding descriptions of the model in the third line. Notice what is captured by the individual counterpart. In Luce’s model, this loss is equal to

$$d(x, S) = \hat{p}(x, S) - \hat{p}(x, X) = \frac{w(x)}{w(S)} - w(x) = (1 - w(S))\hat{p}(x, S),$$

where $\hat{p}(x, S)$ is the corresponding Luce probability. In our decomposition, the individual counterpart captures a similar effect, but weighted by $1/(1 + \alpha_i)$.

We make use of this decomposition to infer α_i . One way of achieving this is to make use of a normalization and the decomposition of $d_i(y, S)$ to cancel out the individual counterparts. To this end, take an alternative $y \in S \setminus \{x\}$ and normalize both of the decompositions by the respective observed probabilities as follows and take the difference:

$$\begin{aligned}
 \frac{d_i(x, S)}{p_i(x, S)} &= \frac{\frac{1-w_i(S)}{1+\alpha_i} p_i(x, S)}{p_i(x, S)} + \frac{\frac{\alpha_i}{1+\alpha_i} d_j(x, S)}{p_i(x, S)} \\
 \frac{d_i(y, S)}{p_i(y, S)} &= \frac{\frac{1-w_i(S)}{1+\alpha_i} p_i(y, S)}{p_i(y, S)} + \frac{\frac{\alpha_i}{1+\alpha_i} d_j(y, S)}{p_i(y, S)} \\
 \frac{d_i(x, S)}{p_i(x, S)} - \frac{d_i(y, S)}{p_i(y, S)} &= \frac{\alpha_i}{1 + \alpha_i} \left[\frac{d_j(x, S)}{p_i(x, S)} - \frac{d_j(y, S)}{p_i(y, S)} \right]. \tag{3}
 \end{aligned}$$

Equation (3) reveals α_i uniquely whenever there exists (x, y, S) such that $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) \neq 0$. Within the proof of Theorem 1, we show that there always exist (x, y, S) such that this condition holds, as long as $p_1 \neq p_2$. For the inference of $w_i(x)$, we simply make use of the description of the model for choices from X , yielding: $w_i(x) = p_i(x, X) + \alpha_i(p_i(x, X) - p_j(x, X))$. Obviously each $w_i(x)$ is identified uniquely with $\sum_X w_i(x) = 1$. Let us state these results in a proposition for completeness purposes.

PROPOSITION 1. *Let $p_1 \neq p_2$ and (p_1, p_2) have a dual interaction representation. Then, $(w_1, w_2, \alpha_1, \alpha_2)$ that represent (p_1, p_2) are identified uniquely.*

Identification above relies on the availability of data from two sets, the universal set X and any other menu S with at least two alternatives. This begs the question whether it is possible to do any inference when choices from X are not available? Indeed, it is possible to recover the parameters from pairs of sets as long as they have at least two common elements, although the identification strategy gets slightly more complicated.

To see how, let any two distinct sets S, T with $x, y \in S \cap T$ and $S \cup T = X$ and reproduce equation (3) for any two such S, T , as $d_i(x, S, T) = p_i(x, S) - p_i(x, T)$

$$\begin{aligned} &= \frac{w_i(T) - w_i(S)}{w_i(T) + \alpha_i} p_i(x, S) + \frac{w_i(x) + \alpha_i p_j(x, S)}{w_i(T) + \alpha_i} - \frac{w_i(x) + \alpha_i p_j(x, T)}{w_i(T) + \alpha_i} \\ &= \underbrace{\frac{w_i(T) - w_i(S)}{w_i(T) + \alpha_i} p_i(x, S)}_{\text{individual}} + \underbrace{\frac{\alpha_i}{w_i(T) + \alpha_i} d_j(x, S, T)}_{\text{social influence}}. \end{aligned}$$

Normalizing the decompositions for distinct $x, y \in S$ and taking the difference will result in

$$\frac{d_i(x, S, T)}{p_i(x, S)} - \frac{d_i(y, S, T)}{p_i(y, S)} = \underbrace{\frac{\alpha_i}{w_i(T) + \alpha_i}}_{\gamma_i(x, y, S, T)} \left[\frac{d_j(x, S, T)}{p_i(x, S)} - \frac{d_j(y, S, T)}{p_i(y, S)} \right].$$

Thus, two identifying equations are

$$\gamma_i(x, y, S, T) = \frac{\alpha_i}{w_i(T) + \alpha_i} \quad \text{and} \quad \gamma_i(x, y, T, S) = \frac{\alpha_i}{w_i(S) + \alpha_i}. \quad (4)$$

Unlike the case with data from X , we now have one too many parameters for unique identification only from γ_i s. The third identity, we need comes from the normalization assumption $w_i(X) = 1$. Yet as the behavior from X is not observed, we need to decompose it consistently over S and T . Since $w_i(S) + w_i(T \setminus S) = 1$, by definition of the model $w_i(x) = [\alpha_i + w_i(T)]p_i(x, T) - \alpha_i p_j(x, T)$ yields

$$w_i(T \setminus S) = [\alpha_i + w_i(T)] \sum_{x \in T \setminus S} p_i(x, T) - \alpha_i \sum_{x \in T \setminus S} p_j(x, T) = 1 - w_i(S),$$

resulting in the last equation sufficient for unique identification combined with the two above.

We shall note that the requirement $S \cup T = X$ is not strictly necessary for identification without choice data from X . Since we cannot speculate about underlying parameters without observing some data involving all variables, the identification requires some observations covering X . Specifically, in addition to identification equations (4), more data revealing $w_i(S \cup T)$ is required. Whenever $S \cup T = X$, the normalization $w_i(X) = 1$ comes to aid. Whenever $S \cup T \neq X$, any additional observation revealing $w_i(X \setminus (S \cup T))$ should be sufficient for identification of α_1 and α_2 .

2.3. Falsifiability

For identification, we assumed a pair of choice behaviors (p_1, p_2) consistent with the dual interaction model. We now need to express explicitly how one can detect the consistency of the data with the model. In other words for given (p_1, p_2) , which

properties of these behaviors ensure that these two individuals are behaving as if they are choosing according to dual interaction model?

We have three falsifiable characterizing properties built around the decomposition of $d_i(x, S)$ into individual and social counterparts as we have used in Section 2.2. Specifically, for any $S \neq X$ and $x \in S$, $d_i(x, S)$ is composed of two counterparts: the individual effect (as there are more options in X than S for i 's attraction) and the social influence effect (same goes for j 's attraction).

Our characterizing properties build on the premise that one can eliminate the unobserved individual effects for $x \in S$ by cancelling them out with those of $d_i(y, S)$ for some distinct $y \in S$. The remainder will then be a function of the social influence effect. Specifically, it will be a linear function. Formally, take any S and $x, y \in S$ with $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) \neq 0$ and define $\beta_i(x, y, S)$ as follows:

$$\frac{d_i(x, S)}{p_i(x, S)} - \frac{d_i(y, S)}{p_i(y, S)} = \beta_i(x, y, S) \left[\frac{d_j(x, S)}{p_i(x, S)} - \frac{d_j(y, S)}{p_i(y, S)} \right]. \quad (5)$$

Three properties that impose conditions on these two variables $\beta_1(x, y, S)$ and $\beta_2(x, y, S)$ are sufficient for the characterization of the dual interaction model.

Independence [I]. $\beta_i(x, y, S) (= \beta_i)$ is independent of S, x, y . Moreover, β_i satisfies equation (5) for all $S \neq X$ and distinct $x, y \in S$.

Uniform Boundedness [UB]. $\beta_i(x, y, S) < \min_{z \in X} \left\{ \frac{p_i(z, X)}{p_j(z, X)} \right\}$ for all S and distinct $x, y \in S$.

Non-negativeness [Nn]. $\beta_i(x, y, S) \geq 0$ for all S and distinct $x, y \in S$.

Independence is the property that restores the additive linear influence structure among individuals. $\beta_i(x, y, S)$ is defined for all those observations with a non-zero $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S)$. The first part of Independence ensures that $\beta_i(x, y, S)$ is indeed constant across observations, hence, defining β_i . The second part of Independence guarantees that this β_i satisfies equation (5) even for those observations with $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) = 0$. Uniform Boundedness guarantees that idiosyncratic evaluations of alternatives, w_i , are positive. This is due to the choice of $\alpha_i := \beta_i/(1 - \beta_i)$ and $w_i(x) := p_i(x, X) + \alpha_i(p_i(x, X) - p_j(x, X))$, as revealed in Section 2.2. These two equations jointly imply

$$\frac{p_i(x, X)}{p_j(x, X)} = \frac{w_i(x) + \alpha_i p_j(x, X)}{(1 + \alpha_i) p_j(x, X)} = \frac{w_i(x)}{(1 + \alpha_i) p_j(x, X)} + \frac{\alpha_i}{1 + \alpha_i}.$$

Hence, by UB

$$\beta_i = \frac{\alpha_i}{1 + \alpha_i} < \min_{x \in X} \left\{ \frac{w_i(x)}{(1 + \alpha_i) p_j(x, X)} + \frac{\alpha_i}{1 + \alpha_i} \right\},$$

ensures that $w_i(x) > 0$ for all x . And finally, Non-negativeness restricts the interaction among individuals to conformity behavior rather than diversification.

The characterization result is stated for pairs of stochastic choice rules with some variation in the overall behavior, that is, $p_1 \neq p_2$. This is because having exactly the same behavior in any choice set might be due to identical preferences of 1 and 2, that is, $w_1 = w_2$; or it might be because one of the individuals only cares about imitating the other individual. It is not possible to distinguish between these cases without any additional information, such as their choice behavior in isolation.

THEOREM 1. *Let $p_1 \neq p_2$. Then, (p_1, p_2) has a dual interaction representation if and only if it satisfies Independence, Uniform Boundedness, and Non-negativeness.*

The proof constructs the model thanks to the structure granted by Independence and by the help of restrictions imposed by the remaining two axioms. We take $\alpha_i(x, y, S) := \beta_i / (1 - \beta_i)$ (well-defined by the first two properties and non-negative by the latter two) and $w_i(x) := p_i(x, X) + \alpha_i(p_i(x, X) - p_j(x, X))$ (positive by Uniform Boundedness). We then show that for any S and $x, y \in S$, Independence builds up to

$$\frac{p_i(x, S)}{p_i(y, S)} = \frac{w_i(x) + \alpha_i p_j(x, S)}{w_i(y) + \alpha_i p_j(y, S)}.$$

The fact that this holds for each pair of alternatives immediately gives us the dual interaction model.

Theorem 1 is a strong result. Three properties over $\beta_i(\cdot)$ are necessary and sufficient to confirm if two individuals are choosing consistently with the dual interaction model. This becomes a straightforward falsification exercise for an observable pair of choice behaviors, (p_1, p_2) , as $\beta_i(\cdot)$ is merely derived from data. Independence is a property very much in the spirit of “constant ratio” properties such as Luce’s IIA. IIA requires that the ratio of choice frequencies of any two alternatives is constant across sets. Similarly, Independence requires that the ratio given by $\beta_i(\cdot)$ for any two alternatives is constant across sets. Certainly, what is captured by β_i is not as straightforward to see as Luce’s ratio; however, we argue that there is subtle behavioral content to β_i . Observe that, $d_i(x, S)/p_i(x, S)$ is the percentage decrease in agent i ’s choice probability of x in expanding S to X . So, $d_i(x, S)/p_i(x, S) - d_i(y, S)/p_i(y, S)$ is a differential in percentage changes. On the other hand, $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S)$ reflects a differential in percentage changes for agent j , normalized by the choice probabilities of i . Thus, the ratio of these two differentials in percentage changes, that is, $\beta_i(x, y, S)$, acts like a differential cross-elasticity of choice probabilities in expanding the set S to X . Independence fixes this differential cross-elasticity for different menus, while the other two properties bound it.

2.4. Stability

The dual interaction model involves an adjustment procedure, where an individual’s evaluation of an alternative is adjusted by the other’s behavior as well as the level of susceptibility to influence. We now embed this adjustment procedure in a

dynamic setting, where individuals start interaction from possibly unrelated behaviors. Specifically, let (p_1^t, p_2^t) denote the behaviors of 1 and 2 at period $t > 0$ and assume that their initial behaviors (p_1^1, p_2^1) are given. One can think of new roommates or teenagers just enrolled in a new school as examples. Below we show that although these individuals start interacting from possibly unrelated behaviors, as long as they adjust consistently, eventually they converge to (p_1^*, p_2^*) , the unique pair of behaviors that the model yields for the given set of parameters. In other words, the behavior produced by the dual interaction model constitutes a stable equilibrium when embedded in a dynamic environment.

THEOREM 2. *Take $w_i \in \Delta_{++}(X)$, $\alpha_i \geq 0$, $p_i^*(S) \in \Delta_{++}(S)$ for all $S \in 2^X \setminus \{\emptyset\}$ and for each $i \in \{1, 2\}$ and let $(w_1, w_2, \alpha_1, \alpha_2)$ represent (p_1^*, p_2^*) . Further, let $(p_1^1, p_2^1) \in \Delta(S) \times \Delta(S)$. Define for each $i \in \{1, 2\}$ and $t \geq 2$, $p_i^t(\cdot, S) \in \Delta(S)$ via*

$$p_i^t(x, S) \equiv \frac{w_i(x) + \alpha_i p_j^{t-1}(x, S)}{\sum_{y \in S} w_i(y) + \alpha_i p_j^{t-1}(y, S)}.$$

Then, for each $i \in \{1, 2\}$, $\lim_{t \rightarrow \infty} p_i^t = p_i^$.*

An interesting implication of this dynamic environment involves identification. Although the observed behavior changes over time, because it changes in a consistent way, our identification strategy still holds for the underlying preferences and interaction parameters $(w_1, w_2, \alpha_1, \alpha_2)$. Similar to the static setting, the data requirement is minimal: Only choice behavior from two different sets need be observed. However, since now observations are from different time periods, the inference of α_i demands data from two successive periods.

PROPOSITION 2. *Let $(p_1^{t-1}, p_2^{t-1}, p_1^t, p_2^t)$ such that for each $i \in \{1, 2\}$ and $p_i^t(\cdot, S) \in \Delta(S)$*

$$p_i^t(x, S) \equiv \frac{w_i(x) + \alpha_i p_j^{t-1}(x, S)}{\sum_{y \in S} w_i(y) + \alpha_i p_j^{t-1}(y, S)}.$$

Then, $(w_1, w_2, \alpha_1, \alpha_2)$ that represent (p_1, p_2) are identified uniquely.

2.5. Foundations

Why does the dual interaction model make sense as a decision procedure that incorporates social influence? We provide three different foundational justifications, three different mechanisms that produce behavior consistent with the dual interaction model. Each environment differs from the classical stochastic choice setting. To this end, we strip the menu-richness of the choice argument away and focus on a single budget set, say X . We suppress the menu dependence in the notation of this subsection. All of the following can be reproduced for any menu S .

The first mechanism, we introduce reproduces dual interaction as the equilibrium of a game, whereas the second one incorporates individual utility maximization in a discrete choice setting with peer effects. The main link between these two and our model is built around the use of a logistic distribution. However, as we show in the third mechanism, the logistic set up is dispensable. This last part introduces a simple naive learning mechanism that also reproduces dual interaction behavior in the limit.

2.5.1. Game Theoretic Foundations. Dual interaction model envisions individual behavior contingent on peer behavior, which naturally relates to a game set up. Thus, the first question we investigate is whether the pair of behaviors produced by the dual interaction model could also be rationalized by an underlying game. Indeed, we show that, a very specific solution concept for normal form games, the quantal response equilibrium (McKelvey and Palfrey 1995), also reproduces the behavior granted by our model. To see this, consider a normal form game with two players 1 and 2, with $S = S_1 \times S_2 = X \times X$ as the set of strategy profiles and s_i represents a pure strategy for player i . Let Σ_i denotes the set of probability distributions over S_i and an element $\sigma_i \in \Sigma_i$ is a mixed strategy, and $\sigma_i(s_i)$ is the probability that player i chooses pure strategy s_i with Σ as the set of mixed strategy profiles. The pay-off functions $u_i : S \rightarrow \mathfrak{R}$ are such that $u_i(x, y)$ represents the utility of player i when player 1 consumes x and player 2 consumes y . In particular, assume that $u_1(s) = u_1(x, y) = w_1(x) + \alpha_1 1\{x = y\}$ and $u_2(s) = u_2(x, y) = w_2(y) + \alpha_2 1\{y = x\}$. In other words, each player receives a consumption utility $w_i(x)$ and additional utility α_i when their consumptions match. With positive α , this corresponds to a very simple form of pay-off function for conformity games. For instance, consider classroom behavior of students: Asking a question “feels easier” when someone else does so (Alessio and Kilgour 2011) or negative behavior such as aggression becomes more rewarding in the presence of aggressive peers (Hanish et al. 2005).

Hence, for each mixed-strategy profile $\sigma \in \Sigma$, player i 's expected payoff is $u_i(\sigma) = \sum_{s \in S} \sigma_i(s_i) \sigma_j(s_j) u_i(s)$, and the expected payoff for adopting the pure strategy s_i when the other player uses σ_j is $u_i(s_i, \sigma_j) = \sum_{s_j \in S_j} \sigma_j(s_j) u_i(s_i, s_j) = \sigma_j(s_i) (w_i(s_i) + \alpha_i) + (1 - \sigma_j(s_i)) w_i(s_i) = w_i(s_i) + \alpha_i \sigma_j(s_i)$. Under the assumption that $U_i(s_i, \sigma_j) = u_i(s_i, \sigma_j) \varepsilon_{iS}$ with i.i.d. Log-logistic errors (i.e. $\log \varepsilon_i$ follows a Type 1 extreme value distribution), the QRE outcome coincides with (p_1, p_2) of the dual interaction model. The standard stochastic derivation is provided in Online Appendix B.

Two caveats must be mentioned: First, the QRE is a prediction for a single game, whereas the testable implications of our model derive their power from the ability to observe behavior *across* choice sets. Indeed, QRE affords basically no predictions on a single-game (much like classical choice theory generates no predictions from a single budget). See, for example, Haile, Hortaçsu, and Kosenok (2008). Thus, a suitable extension of the notion of QRE *across* game forms must be described.¹⁸ Second, our

18. In particular, one must take care to ensure the error distributions across game forms coincide in a natural way.

model results from a very specific choice of error distribution (one of the parameters of the QRE model) and a very specific choice of utility (the other main parameter). To sum up, the behavior produced by our model may be viewed as being *rationalized* by a particular choice of game forms and the logit QRE solution concept, suitably extended to across games. We believe exploration of similar results for generic games of peer influence with standard equilibrium concepts remains as an interesting open question outside the scope of this paper.¹⁹

2.5.2. Random Utility with Linear Social Interactions. The standard econometric tools to study social interactions include discrete choice models with peer effects (Blume 1993; Brock and Durlauf 2001, 2006). These models regard individual utility as a linear additive function of observed and unobserved individual characteristics as well as social influence. Under the assumption of i.i.d. extreme value unobserved characteristics, utility maximization yields choice frequencies as a function of individual characteristics and social influence. The dual interaction model can also be reproduced in a multinomial discrete choice setting. Two specific assumptions are sufficient to achieve this: a logarithmic transformation of the utility and a relevant extreme value distribution. To see how this works, assume a multiplicative form for individual utility as follows:

$$U_i(x) = V_i(x)\varepsilon_i(x) \quad \text{where} \quad V_i(x) = w_i(x) + \alpha_i p_j(x).$$

Similar to the previous subsection (and as by step by step derivation provided in Online Appendix B), under the assumption that ε_i follows a log-logistic distribution, maximization of $\log U_i(x)$ results in $p_i(x)$, exactly as given by the dual interaction model. Thus, a logarithmic transformation of the individual utility and a relevant extreme value distribution for the error terms in a discrete choice setting with social interactions lead to the behavior described by the dual interaction model.

According to Blume et al. (2011) empirical challenges to identification of social interactions are broadly grouped under three categories: (i) simultaneous equation problem: How to differentiate the direct interdependencies between choices from the effects of predetermined social factors; (ii) unobserved group-level characteristics; and (iii) endogeneity of reference groups and self-selection. The primary aim of our social interaction model for identification purposes is the revelation of the direct interdependencies between choices. Those are captured by the interaction parameter, α_j . Since our model lives in a two-parameter world, all other effects are left to be captured by the preference parameter w_j . This approach enables us to tackle the simultaneous equation problem of (i), “the reflection problem”, by identifying the

19. The extensive literature on peer influence games over social networks (Ballester, Calvo-Armengol, and Zenou 2006; Calvo-Armengol, Patacchini, and Zenou 2009) does not provide an immediate answer to this question, mostly because the multi-variate discrete nature of our setting and the assumption that main observables are stochastic choice outcomes over different menus.

endogenous effects and abstracting away from observed or unobserved group level characteristics, namely, contextual and correlated effects.²⁰

In order to address challenges belonging to (ii) or (iii) and investigate the effects of predetermined social factors, one approach could be further exploring heterogeneities over w_i (and/or α_i). For instance, take the issue of homophily, the tendency to create social ties with people who are similar to one's self (McPherson, Smith-Lovin, and Cook 2001; Blackwell and Lichter 2004; Currarini, Jackson, and Pin 2009). This is an endogenous reference group formation problem and is not immediate to identify out of observable behavior. However, our model reduces homophily to the similarity of underlying w_i parameters for people with high α_i values. In other words, our identification strategy can be helpful to identify homophilic interactions by comparing the revealed w_i 's. Certainly, this becomes a more interesting question in a multi-individual setting, as we explore in Section 3.

One final potential challenge that may arise in our setting but not listed explicitly within the above categories is due to the exogenous menu variation across individuals. We assume that individuals choose from the same menus of alternatives, and our entire identification strategy is based on menu variation. However, in cases the menus available to individuals are correlated with the idiosyncratic unobservables, this critical assumption fails. Hence, the dual interaction representation will not be useful for identification with endogenous menu variation.

2.5.3. Naive Learning with Anchors. The previous two subsections have explored the rational and/or strategic motivations underlying dual interaction mechanism. However, adopting the behavior dictated by the dual interaction model does not necessitate adopting standard notions of full rationality. Indeed, dual interaction model can also be reproduced in a particular boundedly rational learning setting. The most well-known model of naive learning over social networks, the DeGroot model, envisions a non-Bayesian updating of individual beliefs by repeatedly taking weighted averages of one's neighbors' beliefs (DeGroot 1974; Golub and Jackson 2010). The behavior produced by the dual interaction model is observationally equivalent to the limit of a DeGroot updating process with anchors. In this setting, w_1 and w_2 act as anchors, as innate preferences/beliefs that do not change over time. At each point in time, the individuals update their behavior by taking a weighted average of their peers' behavior and their own anchor, with time invariant weighting. In the limit, this updating converges to the behavior produced by the dual interaction model. We leave the detailed derivation of this mechanism to Online Appendix C.

Overall, these three settings indicate that behavior postulated by our model can be justified by an underlying utility maximization as well as a naive learning mechanism. The main difference of our model lies in the menu variability of our setting. Our model is a stochastic choice model that assumes consistent behavior across menus. Critically,

20. See Brock and Durlauf (2007) for identification of correlated effects in discrete choice social interaction models and Bramoullé, Djebbari, and Fortin (2020) for a recent survey of the methods developed to address it.

this menu variability grants us unique identification of the underlying unobserved parameters.

3. Multi-Agent Interaction

One of the strengths of our model is that it is easily generalizable to multi-individual setting with more intricate forms of social interactions. We can easily capture the heterogeneities that drive different behavioral outcomes in a social context. Not only individuals have different preferences but they also have different levels of susceptibility to influence. Or similarly, different people might influence an individual in different ways. The generalization of our model to multi-individual setting allow for these variations, by providing a complementary approach to the identification of social interactions over social networks. In particular, it allows the identification of a weighted social network from choice behavior.

Early works on social networks have assumed known network structure, based on common observables or self-reported, elicited data (Bramoullé, Djebbari, and Fortin 2009; De Giorgi, Pellizzari, and Redaelli 2010; Lee, Liu, and Lin 2010), that is, rather costly to collect (De Paula 2017). A first improvement on this was suggested by Blume et al. (2015) by assuming only partial information on the structure of the underlying network. De Paula, Rasul, and Souza (2019) advance on this by assuming no a priori information on the network structure and provide sufficient conditions for full identification of social interactions with panel data. Similarly, our generalized model does not require any exogenous network structure. On the contrary, our representation theorem reveals the unknown network of social influence in addition to individual preferences and influence patterns. Specifically, given the behavior of a group of individuals that is consistent with our characterizing properties, we can *uniquely* identify the underlying preferences, represented by w_i , and the interaction pattern, represented by α_{ij} , capturing how individual i is influenced by the behavior of individual j for all pairs of individuals i and j . Note that the interaction between i and j might be asymmetric, that is, α_{ij} need not be equal to α_{ji} .

Let us now formally introduce the multi-individual model. Let N denote a set of $n < +\infty$ individuals interacting. As before, for each choice problem, $S \in 2^X \setminus \emptyset$, we observe agent i 's stochastic choice, $p_i(x, S)$. Let $\mathbf{p}_{-i}(x, S) \in \mathfrak{R}^{n-1}$ denote the vector of $p_j(x, S)$ and $\mathbf{d}_{-i}(x, S) \in \mathfrak{R}^{n-1}$ the vector of $d_j(x, S)$ for all $j \neq i$.

DEFINITION 2. (p_1, p_2, \dots, p_n) has a social interaction representation if for each $i \in N$ there exist $w_i \in \Delta_{++}(X)$ and $\alpha_i \in \mathfrak{R}_+^{n-1}$ such that

$$p_i(x, S) = \frac{w_i(x) + \alpha_i \cdot \mathbf{p}_{-i}(x, S)}{\sum_{y \in S} [w_i(y) + \alpha_i \cdot \mathbf{p}_{-i}(y, S)]}$$

for all $x \in S$ and for all S .

The parameter α_i captures different levels of susceptibility to influence from different individuals, that is, agent i can be influenced differently by different j 's. Let α_{ij} denotes the entry of α_i relating to the influence of individual j on i . If $\alpha_{ij} = 0$ for all $j \neq i$, then once again i 's choice behavior reduces down to the Luce.

The identification strategy and the characterizing properties are similar to those of the baseline model. Notice that for any $S \neq X$, and any two distinct $x, y \in S$, now there might be multiple vectors $\gamma_i \in \mathfrak{R}^{n-1}$ satisfying the following equation:

$$\gamma_i \cdot \left(\frac{d_{-i}(x, S)}{p_i(x, S)} - \frac{d_{-i}(y, S)}{p_i(y, S)} \right) = \frac{d_i(x, S)}{p_i(x, S)} - \frac{d_i(y, S)}{p_i(y, S)}. \tag{6}$$

We will be interested in the ones that satisfy it for all observations.

$$\mathcal{B}_i = \{\gamma_i \in \mathfrak{R}^{n-1} \mid \gamma_i \text{ solves (6) for any } S \text{ and distinct } x, y \in S\}$$

The first characterizing property ensures that \mathcal{B}_i is non-empty; hence, there is at least one solution to the system of equations given by equation (6) for all S and $x, y \in S$. The last one puts bounds on it.

N-Independence [N-I]. \mathcal{B}_i is non-empty.

N-Positive Uniform Boundedness. [N-PUB]. $p_i(z, X) > \gamma_i \cdot p_{-i}(z, X)$ for some $\gamma_i \in \mathcal{B}_i$ with $\gamma_i \in \mathfrak{R}_+^{n-1}$, for all $z \in X$.

N-Independence implies that there exists a vector, say β_i , that satisfies equation (6) independent of S, x, y . As before, α_i is to be identified from β_i . Specifically, $\alpha_{ij} = \beta_{ij} / (1 - \sum_{j \neq i} \beta_{ij})$. However, unique identification requires more than two observations this time, simply because there are more unknowns now. Indeed, equation (6) has $(n - 1)$ unknowns, α_{ij} for each $j \neq i$. Hence, the number of linearly independent equations required to solve the system is $(n - 1)$. Notice that this does not mean we necessarily need data from $(n - 1)$ different menus. All that is required is $(n - 1)$ observations; data from two different menus is sufficient as long as there are at least $(n - 1)$ common pairs of alternatives in these two menus.²¹

Unique identification of the underlying preferences is then achieved via

$$w_i(x) = p_i(x, X) + \sum_{j \neq i} \alpha_{ij} [p_i(x, X) - p_j(x, X)]. \tag{7}$$

21. Notice that with n individuals, there are $n(n - 1)$ unknown interaction parameters. Full identification of these requires $(n - 1)$ independent identification equations given by equation (6), which corresponds to observations of $(n - 1)$ pairs of alternatives from at least two different menus. For instance with four individuals, to point identify twelve interaction parameters, observations from $p_i(\{x, y, z\})$ and $p_i(X)$ with $|X| \geq 4$ are sufficient (conditional on linear independence). When the number of alternatives in X is not high enough to consider different pairs, it is possible to use the same pairs of alternatives from a larger number of menus. With 10 individuals, to identify 90 interaction parameters, observations from $p_i(\{x, y, z, t, u\})$ and $p_i(X)$ with $|X| \geq 6$ are sufficient as well as $p_i(\{x, y, z\})$, $p_i(\{x, y, t\})$, $p_i(\{x, z, t\})$ and $p_i(X)$ with $|X| \geq 4$.

THEOREM 3. *Let $\{p_i\}_{i \in N}$. Then, $\{p_i\}_{i \in N}$ has a social interaction representation if and only if N -Independence and N -Positive Uniform Boundedness hold.*

As before, the equilibrium defined by the model always exists and is unique. Moreover, when embedded in a dynamic adjustment process, as in Section 2.4, the limit behavior happens to be the equilibrium defined by our model. The following theorem formalizes these.

THEOREM 4. *Take $w_i \in \Delta_{++}(X)$, $\alpha_{ij} \geq 0$ for all $i, j \in \{1, 2, \dots, n\}$ with $i \neq j$. Then, there is a unique $(p_1^*, \dots, p_N^*) \in \Delta_{++}(S)^N$ for which*

$$p_i^*(x, S) = \frac{w_i(x) + \alpha_i \cdot p_{-i}^*(x, S)}{\sum_{y \in S} [w_i(y) + \alpha_i \cdot p_{-i}^*(y, S)]}$$

and for any $(p_1^1(\cdot, S), \dots, p_N^1(\cdot, S)) \in \Delta_{++}(S)^N$, the iterative map

$$p_i^t(x, S) = \frac{w_i(x) + \alpha_i \cdot p_{-i}^{t-1}(x, S)}{\sum_{y \in S} [w_i(y) + \alpha_i \cdot p_{-i}^{t-1}(y, S)]}$$

converges to (p_1^, \dots, p_N^*) .*

4. Concluding Remarks

The identification of social interactions from observable behavior is an important and highly topical agenda for economists. We believe that the use of choice theoretic tools to study social interactions introduces a new perspective to this problem that has traditionally been dealt with mostly econometric tools.

Exploiting standard choice theoretic tools, this model, and others, should prove useful for the identification of unobservable underlying interaction structures and parameters out of observable behavior. The strength of our identification strategy relies on the novel source of variation we have introduced: The variation of the choice sets. Whether the same insight can be applied into more general settings of interaction constitutes an interesting future research avenue. One potential way to generalize our model is via more flexible definitions of individual utilities a la Luce

$$p_i(x, S) = \frac{U_i(x|S, \alpha_i, p_j)}{\sum_{y \in S} U_i(y|S, \alpha_i, p_j)},$$

where $U_i(x|S, \alpha_i, p_j)$ represents agent i 's utility when she chooses alternative x from budget S . In this paper, we aimed to come up with a particular $U_i(\cdot)$ that produces (p_1, p_2) (i) that is unique for a given set of parameters, (ii) out of which the underlying parameters can be revealed uniquely with an arguably small amount of data, (iii) that is axiomatizable, hence falsifiable, (iv) that is stable when accommodated within a dynamic adjustment process, and (v) that can be produced as the outcome of well-known interaction mechanisms such as a game, parametric social interaction models, or social learning, under appropriate assumptions. Our model assumes that

$U_i(x|S, \alpha_i, p_j)$ is a linear combination of the intrinsic utility and the choice probability of the other. This linearity, combined with the asymmetric role played by the self versus influence over different menus grants us the unique identification. One interesting close alternative would be

$$U_i^*(x|S, \alpha_i, p_j) = w_i(x) + \frac{\alpha_i w_i(S)}{1 - \alpha_i} p_j(x, S).$$

According to this formulation, the decision maker inherently places different weights on the choice probability of others across different menus. What makes this formulation interesting is that it boils down to a convex combination of two Luce models as follows:

$$p_i(x, S) = \lambda_i \frac{w_i(x)}{\sum_{y \in S} w_i(y)} + (1 - \lambda_i) \frac{w_j(x)}{\sum_{y \in S} w_j(y)},$$

where $\lambda_i = (1 - \alpha_i)/(1 - \alpha_i \alpha_j)$. However, this model does not always lend itself to unique identification of the underlying parameters out of observable behavior. We hope that similar results can be obtained by studying different forms of utility, which extend the insights of this paper.

Appendix: Proofs

Proof of Theorem 1.

(\Rightarrow) Let (p_1, p_2) with $p_1 \neq p_2$ have a dual interaction representation with $(w_1, w_2, \alpha_1, \alpha_2)$.

First, we assume that β_i is well-defined and show that equation (5) holds for all x, y and S . Define $\beta_i := (\alpha_i)/(1 + \alpha_i)$. Then, $\beta_i [d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S)]$ is equal to

$$\begin{aligned} &= \frac{\alpha_i}{1 + \alpha_i} \left(\frac{p_j(x, S) - p_j(x, X)}{p_i(x, S)} - \frac{p_j(y, S) - p_j(y, X)}{p_i(y, S)} \right) \\ &= \frac{w_i(x) + \alpha_i p_j(x, S) - w_i(x) - \alpha_i p_j(x, X)}{(1 + \alpha_i) p_i(x, S)} \\ &\quad - \frac{w_i(y) + \alpha_i p_j(y, S) - w_i(y) - \alpha_i p_j(y, X)}{(1 + \alpha_i) p_i(y, S)} \\ &= \frac{(w_i(S) + \alpha_i) p_i(x, S) - (1 + \alpha_i) p_i(x, X)}{(1 + \alpha_i) p_i(x, S)} \\ &\quad - \frac{(w_i(S) + \alpha_i) p_i(y, S) - (1 + \alpha_i) p_i(y, X)}{(1 + \alpha_i) p_i(y, S)} \end{aligned}$$

$$\begin{aligned}
&= \frac{p_i(y, X)}{p_i(y, S)} - \frac{p_i(x, X)}{p_i(x, S)} \\
&= \frac{d_j(x, S)}{p_i(x, S)} - \frac{d_j(y, S)}{p_i(y, S)}.
\end{aligned}$$

Since this holds for all $S \neq X$ and distinct $x, y \in S$, equation (5) holds for all x, y and S .

Now, we show that β_i is indeed well-defined. We have three exhaustive cases. Fix $i, j \in \{1, 2\}$ with $i \neq j$ and first let $\alpha_i \neq 0$. We will show that for some $S \neq X$ and distinct x, y , we have $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) \neq 0$, hence, $\beta_i(x, y, S)$ exists. Assume for a contradiction that $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) = 0$ for all S and distinct x, y . Then,

$$\begin{aligned}
\frac{d_j(x, S)}{p_i(x, S)} - \frac{d_j(y, S)}{p_i(y, S)} = 0 &\Rightarrow \frac{p_j(x, S) - p_j(x, X)}{p_i(x, S)} = \frac{p_j(y, S) - p_j(y, X)}{p_i(y, S)} \\
&\Rightarrow \frac{\alpha_i p_j(x, S) - \alpha_i p_j(x, X)}{p_i(x, S)} \\
&= \frac{\alpha_i p_j(y, S) - \alpha_i p_j(y, X)}{p_i(y, S)} \\
&\Rightarrow \frac{w_i(x) + \alpha_i p_j(x, S) - w_i(x) - \alpha_i p_j(x, X)}{p_i(x, S)} \\
&= \frac{w_i(y) + \alpha_i p_j(y, S) - w_i(y) - \alpha_i p_j(y, X)}{p_i(y, S)} \\
&\Rightarrow \frac{[w_i(S) + \alpha_i] p_i(x, S) - [1 + \alpha_i] p_i(x, X)}{p_i(x, S)} \\
&= \frac{[w_i(S) + \alpha_i] p_i(y, S) - [1 + \alpha_i] p_i(y, X)}{p_i(y, S)} \\
&\Rightarrow \frac{p_i(x, X)}{p_i(x, S)} = \frac{p_i(y, X)}{p_i(y, S)}.
\end{aligned}$$

But since this holds for all S, x, y , then IIA would be satisfied, establishing a contradiction with $\alpha_i \neq 0$. Now consider $\alpha_i = 0$ and $\alpha_j \neq 0$. Then, p_i has a Luce representation and $d_i(x, S)/p_i(x, S) - d_i(y, S)/p_i(y, S) = 0$ for all S and $x, y \in S$. We now show that for some S and distinct $x, y \in S$, $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) \neq 0$ so that I is satisfied for $\beta_i = \alpha_i/(1 + \alpha_i) = 0$. Assume for a contradiction that for all S and distinct $x, y \in S$, $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) = 0$. Since $\alpha_j \neq 0$, we have

$$\frac{\alpha_j}{1 + \alpha_j} \left(\frac{d_i(x, S)}{p_j(x, S)} - \frac{d_i(y, S)}{p_j(y, S)} \right) = \frac{d_j(x, S)}{p_j(x, S)} - \frac{d_j(y, S)}{p_j(y, S)} \quad (\text{A.1})$$

for all S and distinct $x, y \in S$, as we have shown above. Take S and $x, y \in S$ with $d_i(x, S)/p_j(x, S) \neq d_i(y, S)/p_j(y, S)$ and substitute $d_j(x, S)$ by $d_j(y, S)p_i(x, S)/p_i(y, S)$ in equation (A.1):

$$\begin{aligned} \frac{\alpha_j}{1 + \alpha_j} \left(\frac{d_i(x, S)}{p_j(x, S)} - \frac{d_i(y, S)}{p_j(y, S)} \right) &= \frac{d_j(y, S)p_i(x, S)}{p_j(x, S)p_i(y, S)} - \frac{d_j(y, S)}{p_j(y, S)} \\ &= \frac{\alpha_j}{1 + \alpha_j} \left(\frac{d_i(x, S)}{p_j(x, S)} - \frac{d_i(y, S)}{p_j(y, S)} \right) \\ &= \frac{d_j(y, S)p_i(x, S)p_j(y, S) - d_j(y, S)p_j(x, S)p_i(y, S)}{p_j(x, S)p_i(y, S)p_j(y, S)} \\ \frac{\alpha_j}{1 + \alpha_j} &= \frac{d_j(y, S)[p_i(x, S)p_j(y, S) - p_i(y, S)p_j(x, S)]}{p_i(y, S)[d_i(x, S)p_j(y, S) - d_i(y, S)p_j(x, S)]}. \end{aligned}$$

As p_i has a Luce representation, $d_i(x, S) = p_i(x, S)(1 - w_i(S))$. We can then simplify the expression as follows:

$$\frac{\alpha_j}{1 + \alpha_j} = \frac{d_j(y, S)}{p_i(y, S)(1 - w_i(S))} = \frac{d_j(y, S)}{d_i(y, S)}.$$

But then,

$$\begin{aligned} \frac{\alpha_j}{1 + \alpha_j} = \frac{d_j(y, S)}{d_i(y, S)} &\Rightarrow \frac{\alpha_j p_i(y, S) - \alpha_j p_i(y, X)}{1 + \alpha_j} = p_j(y, S) - p_j(y, X) \\ &\Rightarrow \frac{w_j(y) + \alpha_j p_i(y, S) - w_j(y) - \alpha_j p_i(y, X)}{1 + \alpha_j} = p_j(y, S) - p_j(y, X) \\ &\Rightarrow \frac{p_j(y, S)[w_j(S) + \alpha_j] - p_j(y, X)[1 + \alpha_j]}{1 + \alpha_j} = p_j(y, S) - p_j(y, X) \\ &\Rightarrow \frac{p_j(y, S)[w_j(S) + \alpha_j]}{1 + \alpha_j} - p_j(y, X) = p_j(y, S) - p_j(y, X). \end{aligned}$$

Contradiction since $w_j(S) \neq 1$.

Finally, let $\alpha_i = \alpha_j = 0$. We claim that there exists S and distinct $x, y \in S$ such that $d_j(x, S)/p_i(x, S) - d_j(y, S)/p_i(y, S) \neq 0$ so that $\beta_i = \alpha_i/(1 + \alpha_i) = 0$ solves equation (5) for all S and distinct $x, y \in S$. Assume for a contradiction not. Since p_j allows a Luce representation, $d_j(x, S) = (1 - w_j(S))p_j(x, S)$. But then,

$$\frac{d_j(x, S)}{p_i(x, S)} = \frac{d_j(y, S)}{p_i(y, S)} \Rightarrow \frac{p_j(x, S)}{p_i(x, S)} = \frac{p_j(y, S)}{p_i(y, S)}.$$

Since this would be the case for all S and $x, y \in S$, we would have $p_i = p_j$, contradiction. Thus, we have established I for all cases with $\beta_i \equiv \beta_i(x, y, S) = \alpha_i/(1 + \alpha_i)$.

Nn follows directly. UB follows from $w_i(x) > 0$ for all x , since $w_i(x) = (1 + \alpha_i)p_i(x, X) - \alpha_i p_j(x, X)$. Then, we have $p_i(x, X)/p_j(x, X) > \beta_i$, establishing necessity.

(\Leftarrow) Let $p_1 \neq p_2$ satisfy the axioms. Now define $\beta_i \equiv \beta_i(x, y, S)$ by I . UB implies $\beta_i \neq 1$ since otherwise $1 < p_i(x, X)/p_j(x, X)$ for all $x \in X$ yields $p_i(x, X) > p_j(x, X)$, from which it follows that $1 = \sum_{x \in X} p_i(x, X) > \sum_{x \in X} p_j(x, X) = 1$, a contradiction. Since $\beta_i \neq 1$, define $\alpha_i := \beta_i/(1 - \beta_i)$.

We claim that $\alpha_i \geq 0$. Observe that by UB , $\beta_i < 1$. Joint with Nn , this means $\beta_i \in [0, 1)$. Hence, it follows that $\alpha_i = \beta_i/(1 - \beta_i) \geq 0$.

Next, we define weights for each alternative

$$w_i(x) \equiv p_i(x, X) + \alpha_i(p_i(x, X) - p_j(x, X)).$$

Observe that $\sum_{x \in X} w_i(x) = 1$.

Now take any $S \neq X$ with distinct $x, y \in S$. Then,

$$\begin{aligned} \frac{d_i(x, S)}{p_i(x, S)} - \frac{d_i(y, S)}{p_i(y, S)} &= \frac{\alpha_i}{1 + \alpha_i} \left[\frac{d_j(x, S)}{p_i(x, S)} - \frac{d_j(y, S)}{p_i(y, S)} \right] \\ \frac{p_i(y, X)}{p_i(y, S)} - \frac{p_i(x, X)}{p_i(x, S)} &= \alpha_i \left[\frac{d_j(x, S) - d_i(x, S)}{p_i(x, S)} - \frac{d_j(y, S) - d_i(y, S)}{p_i(y, S)} \right] \\ \frac{p_i(x, X) + \alpha_i d_j(x, S) - \alpha_i d_i(x, S)}{p_i(x, S)} &= \frac{p_i(y, X) + \alpha_i d_j(y, S) - \alpha_i d_i(y, S)}{p_i(y, S)}. \end{aligned}$$

Now add α_i to both sides of this equality and notice that as $-\alpha_i d_i(x, S) + \alpha_i p_i(x, S) = \alpha_i p_i(x, X)$, the numerators of both of the sides are non-zero. Hence,

$$\begin{aligned} \frac{p_i(x, S)}{p_i(y, S)} &= \frac{p_i(x, X) + \alpha_i d_j(x, S) - \alpha_i d_i(x, S) + \alpha_i p_i(x, S)}{p_j(y, X) + \alpha_i d_j(y, S) - \alpha_i d_i(y, S) + \alpha_i p_i(y, S)} \\ &= \frac{p_i(x, X) + \alpha_i(p_i(x, X) - p_j(x, X)) + \alpha_i p_j(x, S)}{p_i(x, X) + \alpha_i(p_i(x, X) - p_j(x, X)) + \alpha_i p_j(x, S)} \\ &= \frac{w_i(x) + \alpha_i p_j(x, S)}{w_i(y) + \alpha_i p_j(y, S)}. \end{aligned}$$

Observe in particular that this equality holds even in the case $x = y$. Now, for any $x, y \in S$, we have

$$p_i(y, S) = p_i(x, S) \frac{w_i(y) + \alpha_i p_j(y, S)}{w_i(x) + \alpha_i p_j(x, S)}$$

so that

$$\sum_{y \in S} p_i(y, S) = \sum_{y \in S} p_i(x, S) \frac{w_i(y) + \alpha_i p_j(y, S)}{w_i(x) + \alpha_i p_j(x, S)}.$$

Conclude

$$1 = p_i(x, S) \frac{\sum_{y \in S} (w_i(y) + \alpha_i p_j(y, S))}{w_i(x) + \alpha_i p_j(x, S)}.$$

Consequently,

$$p_i(x, S) = \frac{w_i(x) + \alpha_i p_j(x, S)}{\sum_{y \in S} (w_i(y) + \alpha_i p_j(y, S))}.$$

We finally show that $w_i(x) > 0$ for all $x \in X$. For all $x \in X$, $p_i(x, X)/p_j(x, X) > \beta_i = \alpha_i/(1 + \alpha_i)$. Here, we obtain $(\alpha_i + 1)p_i(x, X) > \alpha_i p_j(x, X)$ for all x . Consequently, $w_i(x) = p_i(x, X) + \alpha_i[p_i(x, X) - p_j(x, X)] > 0$ for all x . \square

Sketch of the Proof of Theorem 2.

Theorem 2 is a special case of Theorem 4 (and Theorem D.2 in Online Appendix D), but there is an especially simple way to grasp the argument, based on contraction mapping. Construct the map $f : \Delta(S) \times \Delta(S) \rightarrow \Delta(S) \times \Delta(S)$, defined by $f_i(p) \equiv (w_i + \alpha_i p_j)/(w_i(S) + \alpha_i)$. Under the complete metric defined by $d((p, p'), (q, q')) = \max\{\|p - p'\|, \|q - q'\|\}$, this map is a contraction with modulus $\max_i(\alpha_i/(w_i(S) + \alpha_i)) < 1$, yielding convergence to p_i^* as defined. The detailed proof of a more general result is provided as the proof of Theorem D.2 in Online Appendix D. \square

Proof of Proposition 2.

Let $(p_1^{t-1}, p_2^{t-1}, p_1^t, p_2^t)$ as defined. Now, let us reproduce equation (3) for this dynamic environment. Take any $S \neq X$ with $x, y \in S$ such that

$$\frac{d_j^{t-1}(x, S)}{p_i^t(x, S)} - \frac{d_j^{t-1}(y, S)}{p_i^t(y, S)} \neq 0$$

and let

$$\beta_i(x, y, S) = \frac{\frac{d_i^t(x, S)}{p_i^t(x, S)} - \frac{d_i^t(y, S)}{p_i^t(y, S)}}{\frac{d_j^{t-1}(x, S)}{p_i^t(x, S)} - \frac{d_j^{t-1}(y, S)}{p_i^t(y, S)}}.$$

(If there does not exist such S , then α_i is revealed as equal to 0, as per argumentation given in the proof of Theorem 1.)

Now, decompose $d_i^t(x, S) = p_i^t(x, S) - p_i^t(x, X)$ as before

$$\begin{aligned} &= \frac{1 - w_i(S)}{1 + \alpha_i} p_i^t(x, S) + \frac{w_i(S) + \alpha_i}{1 + \alpha_i} p_i^t(x, S) - \frac{1 + \alpha_i}{1 + \alpha_i} p_i^t(x, X) \\ &= \frac{1 - w_i(S)}{1 + \alpha_i} p_i^t(x, S) + \frac{w_i(x) + \alpha_i p_j^{t-1}(x, S)}{1 + \alpha_i} - \frac{w_i(x) + \alpha_i p_j^{t-1}(x, X)}{1 + \alpha_i}, \end{aligned}$$

which finally leads to

$$= \underbrace{\frac{1 - w_i(S)}{1 + \alpha_i} p_i^t(x, S)}_{\text{individual}} + \underbrace{\frac{\alpha_i}{1 + \alpha_i} d_j^{t-1}(x, S)}_{\text{social influence}}.$$

The difference between normalized decompositions for distinct $x, y \in S$ yields

$$\frac{d_i^t(x, S)}{p_i^t(x, S)} - \frac{d_i^t(y, S)}{p_i^t(y, S)} = \frac{\alpha_i}{1 + \alpha_i} \left[\frac{d_j^{t-1}(x, S)}{p_i^t(x, S)} - \frac{d_j^{t-1}(y, S)}{p_i^t(y, S)} \right].$$

Hence, we have $\beta_i(x, y, S) = \alpha_i / (1 + \alpha_i)$ as before. Identification of $w_i(x)$ is achieved via $w_i(x) = (1 + \alpha_i)p_i^t(x, X) - \alpha_i p_i^{t-1}(x, X)$. \square

Proof of Theorem 3.

(\Rightarrow) Let (p_1, p_2, \dots, p_n) be a social interaction model. For any i , define $\beta_i \in R^{n-1}$ such that $\beta_{ij} = \alpha_{ij} / (1 + \sum_{j \neq i} \alpha_{ij})$ for all $j \neq i$. We will first show $\beta_i \in \mathcal{B}_i$.

First, let $\alpha_{ij} = 0$ for all i and j with $i \neq j$. Then, for all i , p_i has a Luce representation and hence, $d_i(x, S) = (1 - w_i(S))p_i(x, S)$. Moreover, $d_i(x, S)/p_i(x, S) - d_i(y, S)/p_i(y, S) = 0$ for all S and distinct x, y . Hence, $\beta_i = \mathbf{0}$ is an element in \mathcal{B}_i .

Now, let $\alpha_i \neq \mathbf{0}$ for some i . Take any S and any distinct $x, y \in S$. Then, $\beta_i \cdot \left(\frac{d_{-i}(x, S)}{p_i(x, S)} - \frac{d_{-i}(y, S)}{p_i(y, S)} \right)$ is equal to

$$\begin{aligned} &= \sum_j \frac{\beta_{ij}(p_j(x, S) - p_j(x, X))}{p_i(x, S)} - \sum_j \frac{\beta_{ij}(p_j(y, S) - p_j(y, X))}{p_i(y, S)} \\ &= \sum_j \frac{\alpha_{ij}(p_j(x, S) - p_j(x, X))}{\left(1 + \sum_j \alpha_{ij}\right) p_i(x, S)} - \sum_j \frac{\alpha_{ij}(p_j(y, S) - p_j(y, X))}{\left(1 + \sum_j \alpha_{ij}\right) p_i(y, S)} \\ &= \frac{w_i(x) + \sum_j \alpha_{ij} p_j(x, S) - w_i(x) - \sum_j \alpha_{ij} p_j(x, X)}{\left(1 + \sum_j \alpha_{ij}\right) p_i(x, S)} \\ &\quad - \frac{w_i(y) + \sum_j \alpha_{ij} p_j(y, S) - w_i(y) - \sum_j \alpha_{ij} p_j(y, X)}{\left(1 + \sum_j \alpha_{ij}\right) p_i(y, S)} \end{aligned}$$

and hence,

$$\begin{aligned}
 &= \frac{p_i(x, S) \left[w_i(S) + \sum_j \alpha_{ij} \right] - p_i(x, X) \left[1 + \sum_j \alpha_{ij} \right]}{\left(1 + \sum_j \alpha_{ij} \right) p_i(x, S)} \\
 &\quad - \frac{p_i(y, S) \left[w_i(S) + \sum_j \alpha_{ij} \right] - p_i(y, X) \left[1 + \sum_j \alpha_{ij} \right]}{\left(1 + \sum_j \alpha_{ij} \right) p_i(y, S)} \\
 &= \frac{\left[w_i(S) + \sum_j \alpha_{ij} \right]}{\left(1 + \sum_j \alpha_{ij} \right)} - \frac{p_i(x, X)}{p_i(x, S)} - \frac{\left[w_i(S) + \sum_j \alpha_{ij} \right]}{\left(1 + \sum_j \alpha_{ij} \right)} + \frac{p_i(y, X)}{p_i(y, S)} \\
 &= \frac{p_i(y, X)}{p_i(y, S)} - \frac{p_i(x, X)}{p_i(x, S)},
 \end{aligned}$$

establishing $\beta_i \in \mathcal{B}_i$.

Certainly, $\beta_i \in R_+^{n-1}$ as $\alpha_{ij} \geq 0$ for all i, j with $i \neq j$. *N-PUB* then follows from $w_i(x) > 0$ for all x , since $w_i(x) = p_i(x, X) + \sum_{j \neq i} \alpha_{ij} (p_i(x, X) - p_j(x, X)) > 0 \Rightarrow (1 + \sum_{j \neq i} \alpha_{ij}) p_i(x, X) > \sum_{j \neq i} \alpha_{ij} p_j(x, X) \Rightarrow p_i(x, X) > \beta_i \cdot \mathbf{p}_{-i}(x, X)$.

(\Leftarrow) Take (p_1, p_2, \dots, p_n) satisfying our axioms. Take any $i \in N$, x, y and S and by *N-I*, take $\beta_i \in \mathcal{B}_i$, which also satisfies *N-PUB*. Further, define $\alpha_i \in R^{n-1}$ such that $\alpha_{ij} = \beta_{ij} / (1 - \sum_{j \neq i} \beta_{ij})$. We first show that α_i is well-defined and non-negative since $\sum_{j \neq i} \beta_{ij} < 1$. This is because by *N-PUB*, $p_i(x, X) > \beta_i \cdot \mathbf{p}_{-i}(x, X)$ for all x , we have $1 = \sum_{x \in X} p_i(x, X) > \sum_{x \in X} \beta_i \cdot \mathbf{p}_{-i}(x, X) = \sum_{j \neq i} \beta_{ij}$. Hence, $\alpha_i \in R_+^{n-1}$ is well-defined for all β_i as claimed.

Notice we then have $[1 / (1 + \sum_{j \neq i} \alpha_{ij})] \alpha_i = \beta_i$. Now define $w_i(x) := p_i(x, X) + \alpha_i \cdot [p_i(x, X) \mathbf{1} - \mathbf{p}_{-i}(x, X)]$, where $\mathbf{1} \in R^{n-1}$ is a vector of ones and observe that

$$\begin{aligned}
 \sum_{x \in X} w_i(x) &= \sum_{x \in X} (p_i(x, X) + \alpha_i \cdot [p_i(x, X) \mathbf{1} - \mathbf{p}_{-i}(x, X)]) \\
 &= 1 + \alpha_i \cdot \left[\sum_{x \in X} p_i(x, X) \mathbf{1} - \sum_{x \in X} \mathbf{p}_{-i}(x, X) \right] \\
 &= 1 + \alpha_i (\mathbf{1} - \mathbf{1}) = 1.
 \end{aligned}$$

By $N-I$,

$$\begin{aligned} \frac{1}{1 + \sum_{j \neq i} \alpha_{ij}} \alpha_i \cdot \left(\frac{d_{-i}(x, S)}{p_i(x, S)} - \frac{d_{-i}(y, S)}{p_i(y, S)} \right) &= \frac{p_i(y, X)}{p_i(y, S)} - \frac{p_i(x, X)}{p_i(x, S)} \\ &= \frac{(1 + \sum_{j \neq i} \alpha_{ij}) p_i(x, X) + \alpha_i \cdot p_{-i}(x, S) - \alpha_i \cdot p_{-i}(x, X)}{p_i(x, S)} \\ &= \frac{(1 + \sum_{j \neq i} \alpha_{ij}) p_i(y, X)}{p_i(y, S)} + \frac{\alpha_i \cdot p_{-i}(y, S) - \alpha_i \cdot p_{-i}(y, X)}{p_i(y, S)}. \end{aligned}$$

Notice that numerators in both of the sides are positive since $p_j(x, S) > p_j(x, X)$ for all j, x and S . Hence,

$$\begin{aligned} \frac{p_i(x, S)}{p_i(y, S)} &= \frac{p_i(x, X) + \alpha_i \cdot [p_i(x, X)\mathbf{1} - p_{-i}(x, X)] + \alpha_i \cdot p_{-i}(x, S)}{p_i(y, X) + \alpha_i \cdot [p_i(y, X)\mathbf{1} - p_{-i}(y, X)] + \alpha_i \cdot p_{-i}(y, S)} \\ &= \frac{w_i(x) + \alpha_i \cdot p_{-i}(x, S)}{w_i(y) + \alpha_i \cdot p_{-i}(y, S)}. \end{aligned}$$

But then, since this claim holds for all $y \in S$:

$$\begin{aligned} p_i(y, S) &= p_i(x, S) \frac{w_i(y) + \alpha_i \cdot p_{-i}(y, S)}{w_i(x) + \alpha_i \cdot p_{-i}(x, S)} \\ \sum_{y \in S} p_i(y, S) &= \sum_{y \in S} p_i(x, S) \frac{w_i(y) + \alpha_i \cdot p_{-i}(y, S)}{w_i(x) + \alpha_i \cdot p_{-i}(x, S)} \\ 1 &= p_i(x, S) \frac{\sum_{y \in S} [w_i(y) + \alpha_i \cdot p_{-i}(y, S)]}{w_i(x) + \alpha_i \cdot p_{-i}(x, S)} \\ p_i(x, S) &= \frac{w_i(x) + \alpha_i \cdot p_{-i}(x, S)}{\sum_{y \in S} [w_i(y) + \alpha_i \cdot p_{-i}(y, S)]}. \end{aligned}$$

We finally show that $w_i(x) > 0$ for all $x \in X$. This is established by $N-PUB$. Since $p_i(x, X) > \beta_i p_{-i}(x, X)$ and $1 + \sum_{j \neq i} \alpha_{ij} > 0$, then, $(1 + \sum_{j \neq i} \alpha_{ij}) p_i(x, X) > \alpha_i p_{-i}(x, X) \Rightarrow w_i(x) > 0$. \square

Sketch of the Proof of Theorem 4.

Similar to Theorem 2, the proof of this theorem follows from Theorem D.2 in Online Appendix D. Rather than directly use a contraction mapping, the argument leverages results from the theory of matrices. A certain class of iterative linear matrix equations is known to converge as required when the eigenvalues of the relevant matrix have absolute value less than 1. The argument is based on the generalization of the function f constructed in the sketch of the proof of Theorem 2 to multiple individuals: The proof verifies that we can write $f : \prod_i \Delta(S) \rightarrow \prod_i \Delta(S)$ in the form $f(p) = Ap + b$ for some $p \in \mathbb{R}^{|N||S|}$, $A \in \mathbb{R}^{|N||S| \times |N||S|}$, and $b \in \mathbb{R}^{|N||S|}$. We then make use of the model assumptions to establish that all eigenvalues of A have absolute

value less than 1, by a classical result on matrices sometimes called the Gershgorin circle theorem. The extensive proof can be found as the proof of Theorem D.2 in Online Appendix D. \square

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Supplementary data

Supplementary data are available at [JEEA](#) online.