ABOUT THE SELF-DISPLACING PROPHECY

BIANKA VOSSENAAR
(Student Number: 353895)
International Bachelor in Economics and Business Economics (IBEB)

Thesis Supervisor: Jurjen Kamphorst

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SECTION 1: INTRODUCTION

In "Micromotives and Macrobehavior", Thomas C. Schelling (1978) expounded the existence of a certain class of phenomena related to expectations, which he aptly dubbed "Prophecies". The distinction in prophecy classes is made based on how the expectations of certain behavior influence behavior itself and how that in turn affects the expected outcomes. There are three types of prophecies: "self-fulfilling", "self-negating" and "self-displacing".

Schelling described the different self-fulfilling prophecy on the third chapter of the book. The general idea is that certain expectations lead to outcomes that conform to the expectations themselves: "certain expectations are of such character that they induce the kind of behavior that will cause the expectations to be fulfilled". Schelling described three different models of self-confirming expectations (unilateral, reciprocal and selective) that could be further subdivided into two cases; one in which the more something is expected, the more of it will happen and the other one involving critical mass, where everybody expects everybody to hold the same expectations and behave accordingly.

Later in the same section Schelling loosened the definition to describe other models still fitting the "prophecy" phenomena. Those included outcomes that result from expectations but do not necessarily confirm and conform to them, such as the self-negating prophecy (with self-equilibrating or self-correcting expectations and self-confirming signals) and the self-displacing prophecy.

A lot has been said about the self-fulfilling prophecy; perhaps not enough from the others[1]. In this paper I am going to test with an agent-based model whether the self-fulfilling prophecy has a significantly lower speed of convergence towards the upper boundary when there is restricted information about the average.

[1] For a simulation of the "self-negating" prophecy, see (Arthur, 1994).

The structure of the Thesis is as follows: Section 2 elaborates on the self-fulfilling prophecy. Section 3 discusses the game-theoretical form and suggests the use of a Beauty Contest game as a starting point to model the prophecy computationally. Section 4 talks about social interaction and local interaction games. Section 5 gives a small overview of agent-based models and their use in economics. Section 6 introduces the computational model. Section 7 presents the simulation results. Section 8 concludes.

SECTION 2: THE SELF-DISPLACING PROPHECY

A DESCRIPTION

The passage describing the "self-displacing prophecy" is quite brief:

> "Consider the people who want to tip a little above average, to arrive a little ahead of the crowd, to pay slightly higher wages than their competitors, to grade their students above but only slightly above the average grade, or to display slightly more critical capacity than their colleagues in reviewing candidates for admission to graduate school. If everyone shares this motivation, and if everybody expects the same average behavior, they will systematically displace the average from where they thought it would be. **We could call this the *self-displacing prophecy*.** And if everybody not only shares this motivation but suspects everybody else does too, everybody will make allowance for everybody else's bias and adjust his own performance further, aggravating the displacement. Taxicab tips will stabilize at a level where, on the average, people cannot afford to tip above average, but college grades will escalate forever." (Schelling, 1978, p. 118)

I reformulated the passage to prevent future misunderstandings. My interpretation of what was meant is as follows: If everybody expects the average to be 'x', and everybody wants to be above 'x', then 'x' will increase through collective action of independently motivated individuals. The displacement of that average will be aggravated if people jointly suspect everyone else to share the same motivation and collectively adjust their behavior accordingly.

In more abstract terms, the self-displacing prophecy describes a situation in which everybody jointly expects the population to follow a certain distribution, and everybody simultaneously desires to be above (or below) a specific threshold of that distribution (the mean, median etc.). Individuals acting independently but in accordance with that expectation and motivation will collectively alter the distribution, additionally shifting the threshold. And widespread suspicion of common desire will compel people to adjust behavior even further, shifting the threshold more radically or quicker had there been no suspicion. The threshold will either stabilize at the end of a finite boundary, or it will escalate forever.

The Two Versions

Notice that the prophecy has two versions. Version 1 assumes people behave naively since they do not conjecture about other people. In a way, players are not aware of “the game”. They do not strategize; which makes the game quite uninteresting to analyze. Version 2 can incorporate expectations and learning. People are aware or at least suspect others to share their own motivation, but concomitantly believe them to be naïve. Therefore adjustment is a myopic best response. People react to their own expectations about others behavior, not to the expectations other people may also have.

SOME IMPLICIT ASSUMPTIONS

The self-displacing prophecy description bears a couple of implicit assumptions. Such as:

1. Individuals are homogeneous[2]
2. The average is common knowledge
3. Outcomes are certain
4. There are no tradeoffs: players do not “pay” to participate

Such assumptions are, of course, artificial: People are only assumed to be homogeneous in economic models for simplicity. “Information imperfections are pervasive in the economy (Stiglitz, 2002, p. 469)”. “Economic action concerned with the future (…) is often decided upon in a penumbra of doubt and uncertainty” (Lachmann, 1943, p. 1). And of course, everything you do, even your time, has an opportunity cost.

[2] In both preferences and reasoning process

A more realistic example of the self-fulfilling prophecy could be described as follows: picture a class of high-school students looking forward to the SATs. They have no idea how they compare to other students around the country prior to the exam, so they hinge upon their own classmates to determine how well they would fare in such exam relative to the rest. But students are not equally ambitious or talented. Some may want to go to Harvard, while others might want to start a family; in which case a high score is not very important. Furthermore, some might be just worried about a high score, while others about a relative position in the rankings. Therefore students pursue different goals. And although having goals can help achieve positive results; success is (still) not dictated by desire (alone). Even if they all wanted a high score, their performance still depends on their willingness to exert effort/to practice (motivation) as well as their ability to increase their score (skills).

What constitutes a more "realistic approach", however, is debatable. It can be argued that the self-displacing prophecy is predictive of a particular situation. By no means has it implied to encompass all similar situations. There are cases in which it applies; there are cases in which it does not. Therefore, it is beyond the scope of this paper to argue that the self-displacing prophecy is unrealistic.

A MATTER OF PERCEPTION

What is debatable is where the average lies. Who is above it, who is below it and what does it measure? The average is still a matter of perception. By definition, at least some people have to be below the average in any given situation. People can have different views of where the average is or what the average "measures". Perception is highly subjective. The famous example of overconfident drivers comes to mind: most drivers rate themselves above-average when asked. Schelling offers three suggestions of why this might be the case. (1) The perceived average is an arithmetic mean, in which case a big majority can be "above average" if a minority drives badly enough. (2) People use self-serving trait definitions when providing self-evaluations: everybody ranks himself high in qualities he values. (3) "Or some of us are kidding ourselves (Schelling, 1978, p. 65)".

Not everybody can be above the actual average. “Their wishes are individually reasonable but collectively insatiable (Schelling, 1978, p. 66). But it is still a matter of perception where you think you are relative to that average. And therefore also whether you think your tips are above or below the average. Hypothetically, if everybody finds himself to be already above the average, then they will stop tipping higher, and the average tip will stop escalating. Even though the overall average has not yet reached the upper boundary. And if this is a case of “distorted” information, then a similar reasoning can be applied to restricted information. Following a similar argument, the average should take relatively more time to reach the upper boundary when access to information about where the average lies is restricted.

SECTION 3: A GAME-THEORETICAL FORMULATION

The self-displacing prophecy description is nothing more than a game. We can model it in many ways. It was so generally described as to leave much to interpretation. I will use the 'tipping waiters' example to illustrate a two-player game in strategic form. But the results can be extended to a multiplayer game without loss of generality.

Suppose there are two players who **only** care about giving a tip slightly higher than the average tip. They play repeatedly and exhibit Cournot best response dynamics[3], in the sense that they use the average of the previous round (*t-1*) as a reference point to tip in the current round (*t*). Both receive their payoffs with respect to the current round (*t*), so that they win the game only if they manage to tip above the average of that (*t*) round. Assume the average of the previous period is common knowledge and there is a maximum amount both are willing to tip ('z').

What we assume has huge consequences for both payoffs and outcomes, at least theoretically[4]. It is easy to see that there can only be losers in a two-player game if both players know the average was 'x' at (*t-1*), and tip the same above-average 'x+1' amount (for example); because the average of that round (*t*) will effectively be 'x+1'. However, someone can win the game if players tip slightly above the average and differ in the amounts they give[5]. Victory in the short term comes to the player who has a higher willingness to pay or, by chance, tips the highest amount. And in the long run to who has both the highest willingness and ability to pay. The game structure has consequences to who wins the game when; to how far and how fast the average escalates and to where it converges.

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[3] Analogous to what Nagel (1995, p. 1315) described as Cournot behavior: "Giving a best reply to the strategy choices made by the others in the previous period".
[4] Many empirical studies have shown that players deviate from the equilibrium in games. This topic will be further discussed in the "p-Beauty Contest" section of this paper.
[5] Otherwise the Nash Equilibrium is that both tip the highest amount possible ('z'). In which case there can be no winners if 'z' is identical for both players since the situation is equivalent to both tipping the same amount. If 'z' differs, then the player with highest ability and willingness to pay wins.

To see this, suppose two colleagues go out for lunch and decide to split the bill. They have eaten together before, and they always tip 5 euros each to the waiter. On this occasion, both want to signal their generosity and affluence for some reason[6] and therefore wish to tip the waiter above that average. Assume initially players only care about transmitting the signal (i.e. tipping); not about receiving it. They also do not want to discuss the amount of the tip; for that would defeat the signaling purpose. And they can only observe each other's tips after both tips have been given. *(Table 1)* conveys their payoff structure: If both players tip, and tip **equal** above-average amounts, then the average in that round is the same as the amount they tipped[7]. Therefore, cells (A,A) and (B,B) are one and the same and nobody wins. In a game structure like this one, there is only a winner if players act differently.

Table 1	TIP AVERAGE (A)	TIP ABOVE (B)
TIP AVERAGE (A)	(-1, -1)	(-1, 1)
TIP ABOVE (B)	(1, -1)	(-1, -1)

How we describe the problem, of course, matters immensely to how the payoffs are translated. Assume, for instance, that players also care about losing money (unnecessarily). Which is tantamount to saying they pay a fee to play their strategy. Their payoff structure would then look more like *(table 2):* if they tip above the average, both lose the game and their money.

Table 2	TIP AVERAGE	TIP ABOVE
TIP AVERAGE	(-1, -1)	(-1, 1)
TIP ABOVE	(1, -1)	(-2, -2)

[6] Perhaps they fell in love with each other and are both trying to signal that they would be good partners.

[7] If the average at (t-1) = 2; and both players tip 3, then the average at t = 3. Therefore tipping the same amount above the average is equivalent to tipping the average amount.

I could also turn the argument on its head. Players still care about losing money. But instead of having a penchant for tipping more than the polite necessary, players prefer not to tip below the average. Instead of getting utility from tipping above the average, they get disutility from tipping below it. (*Table 3*) shows the payoff structure. Now players do not explicitly "lose" by tipping the average amount. But if one of them decides to tip an above-average amount, then by definition the other player will be giving a below-average tip.

Table 3	TIP AVERAGE	TIP ABOVE
TIP AVERAGE	(0, 0)	(-2, 2)
TIP ABOVE	(2, -2)	(-1, -1)

The self-fulfilling prophecy could also be described as an anti-coordination, non-cooperative game; where it is mutually beneficial for players to adopt different strategies. In a multiplayer game, individual payoffs decrease for every extra player with the same strategy; each additional player creates negative externalities. The structure of anti-coordination games is crucial to its equilibria (Bramoulle, 2002). A model of social interaction with anti-coordination has been previously described by Bramoulle (2007), and 'crowding' is a good example of such a game.

This might sound trivial. On all occasions the outcome is the same. But the self-fulfilling prophecy never specified how players solve the game or that they move simultaneously[8]. Maintaining the previous assumptions, the equilibrium under the tables would possibly be different if the games were played sequentially. In some cases the condition that both would try to tip above the average would not hold anymore[9].

[8] And unless there is some sort of coordination mechanism, it is unlikely that moves would be simultaneous.
[9] It also depends, of course, on when and how the average is updated, and when players declare a victory. If they can declare a victory after their every move, but the average is not updated in synchrony, then both players could tip the same above-average amount and win. Thus they both receive a positive payoff.

The most problematic assumption, of course, is the prophecy itself. Game theorists are mainly interested in the actions of maximizing individuals given the structure of payoffs, and the different types of ensuing equilibria. However, re-creating the self-displacing prophecy is reverse-engineering game theory. The prophecy allows no inference about choices given payoffs. It already assumes people have the same motivation. Player's decisions have already been made for them. So taken to the letter, the prophecy will always hold.

Compare the situation to baking a cake. Like in game theory, you can bake many cakes with a particular recipe. Though similar, they can all be slightly different: you will probably never put the same exact amount of flour in your cakes. If, on the other hand, you start from the cake to know the recipe, then in the end you will have the exact recipe of that particular cake only.

It would be unnecessarily burdensome to illustrate all possible scenarios under which the prophecy holds. In part, whether we observe the outcome predicted by Schelling depends on whether individuals actually make the choices we are predicting them to make. But from analyzing the different games we can create with the prophecy, it is not so clear that it would always happen. There are many ways to make people tip above the average, but not (as) many reasons why they would want to do so. It seems that only in **some** situations would **all** individuals **always want** to tip above the average.

So the real question is whether we can modify the self-displacing prophecy to test the hypothesis, but in a way that it still conforms to its description.

SIMILAR GAMES

The descriptions above resemble other situations. In a first-price sealed-bid auction[10], for example, participants enter once and simultaneously a sealed bid for a certain good. The tender limit is a person's own pockets or their appraisal of the good[11] at that point in time. And the object is sold to the bidder with the highest offer. The real feat, however, is rightly guessing the highest bid (disregarding own offer), and entering a bid slightly above that prediction. For if the winning bid is excessively above the last we could argue that the victory was a pyrrhic one: the famous winners curse.

A more general case, which describes the self-displacing prophecy, a sealed-bid auction bid, and other similar settings, is called the "p-Beauty Contest". It will be presented in more detail in the section below.

[10] Klemperer (1999) gives a broad and thorough overview of the different auctions.

[11] People will not pay more than they think the good is worth. Their appraisal is not only personal, but can include their opinion of what other people think the good is worth, and for how much the object can be resold.

THE P-BEAUTY CONTEST

The beauty contest (BC) was a metaphor Keynes (1936) used to illustrate thought processes of professional investors, who are constantly trying to outwit the crowd. It depicts the expectations and behavior of those who are more concerned with the market price of a certain investment in two months' time than with its underlying value. "We have reached the third degree (of beliefs) where we devote our intelligences to anticipating what average opinion expects the average to be" (Keynes, 1936, p. 156). The metaphor itself alludes to newspaper competitions in which participants have to pick the face closest to the mean preference of all competitors. It was later re-formulated as a game by Moulin (1986) and Nagel (1995), and extended by other economists. Versions of this game include players picking the number closest to a proportion ('p'; either p=1[12], p>1 or 0<p<1) of either the mean, median or maximum of all chosen numbers (p-mean, p-median and p-maximum games).

The most commonly studied version of the beauty contest is the p-mean beauty contest, with p=2/3 (henceforward referred to as the standard beauty contest game (standard BCG)). The idea of the game is simple: players simultaneously pick a number between 0 and 100. The winning "bid" is the number closest to 2/3 (the parameter 'p') of the mean of all chosen numbers. P is common knowledge, and the game is played repeatedly by the same people. Chosen and winning numbers as well as individual payoffs are presented after each round. The theoretical solution can be found by an infinite process of iterated elimination of both weakly dominated strategies and best replies when the number of players is large enough (Grosskopf & Nagel, 2008). The Nash equilibrium of this particular version is for all players to announce zero, or the lowest possible number.

[12] Keynes Beauty Contest metaphor is an example of a p=1 game. However, the p=1 version is less studied than other versions: according to (Nagel, 1995) P=1 is not a particularly interesting version since subjects reasoning steps cannot be distinguished.

PROCESS AND DEPTH OF REASONING IN EMPIRICAL STUDIES

The game is particularly useful to investigate process and depth of reasoning[13]. The Nash equilibrium (NE) is "calculated" under the presumption that people iterate infinitely. But studies consistently find that players deviate from equilibrium choices[14]. And this result is observed even in simple settings. Grosskopf & Nagel (2008) studied a two-person standard BC game. Zero is the weakly dominant strategy and always a "winning" number[15]. Yet, the majority of subjects chose dominated strategies in this context[16]. "Even fairly sophisticated subjects, i.e. game theorists, get it wrong and seem to apply iterated reasoning to the two-person BC game when first confronted with the task" (Grosskopf & Nagel, 2008, p. 94)[17].

To study depth, researchers divide people by levels of reasoning, or n-order beliefs. Players with zero-order beliefs (level-0) either select a strategy at random or pick a personally salient number. Players forming first-order beliefs (level-1) think other people pick at random and chose their best response to this belief. And so on. "A higher value of n indicates more strategic behavior paired with the belief that the other players are also more strategic; the choices converge to the equilibrium play in the limits as n increases" (Nagel, 1995, p. 1315). A number of empirical studies found that people iterate only a few steps[18]. (Nagel, 1995), for example, analyzed depth of reasoning in a standard BCG and found that most people iterate only 2 steps throughout the whole game[19]. Therefore

[13] Or how far people iterate; also called "(higher) n-order beliefs".

[14] See (Duffy & Nagel, 1997), (Bosch-Domenech, Montalvo, Nagel, & Satorra, 2002) and (Nagel, 1995) for experimental research results in Beauty Contest and other games

[15] The smallest number will always win. Regardless of the opponent's choice, you cannot lose by playing zero.

[16] Roughly only 10% of students and of 37% of professionals choose zero in the one-shot two-person standard BCG; and 6% of students and 20% of professionals choose zero in games with more players (Grosskopf & Nagel, 2008).

[17] They suggest that people are largely ignoring their own influence on the mean in the n=2 case. Players familiar with the game could be erroneously transferring their experience from the n>2 situation without thinking, while others might be trying to anchor their answer on their opponent's (a fixed point argument and similar reasoning).

[18] There are many theories of why that is the case. (Bosch-Domenech, Montalvo, Nagel, & Satorra, 2002) analyzed reasoning processes in the BCG games and found that depth of reasoning depended on training, time availability and information-gathering efforts (in the case of experiments done via newspapers). For those who reasoned as far as the equilibrium, their choice also depended on their confidence on others ability to find the equilibrium.

[19] Nagel (1995) found that choices deviate significantly from the equilibrium on the first round; but that they do converge towards it over time (albeit the rate at which it happens varies in different settings). He proposes

choosing the Nash Equilibrium in the first round of the game is rare and would never have led to winning the game.

Analyzing reasoning processes is somewhat unusual in experimental economics, but can shed light in why people deviate from the equilibrium. Bosch-Domenech, Montalvo, Nagel, & Satorra's (2002) paper is particularly interesting because the researchers studied both process and depth of reasoning. They analyzed and divided the data and comments of a standard BCG according to 5 types of reasoning processes[20]. They found that 'iterated best reply to degenerate beliefs (IBRd)' describes subjects' decisions better than 'iterated elimination of dominated strategies (ID)' and is the most prevalent reasoning process across different subject pools, sample sizes and different elicitation methods[21]. Interestingly, almost all subjects who provided comments describing IBRd show only levels 0, 1, 2, 3, and infinity. And the large majority (81%) of subjects describing the NE choose a larger number than NE[22].

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a qualitative learning direction theory to explain the phenomenon, since the hypothesis of increasing iteration steps was rejected. Different learning models have been proposed by others to explain these findings; see (Duffy & Nagel, 1997) and (Camerer, Ho, & Weigelt, 1998).

[20] Namely; a fixed point argument, iterated elimination of weakly dominated strategies [ID], iterated best reply to degenerate beliefs [IBRd] (the player assigns probability 1 to all other players being at one specific level of reasoning), iterated best reply to non-degenerate beliefs [IBRn] (people give positive probabilities to the other players being at more than one level of reasoning) and experimenters (people who realized that through "armchair" reasoning the "right" number could not be found and conducted their own experiments before submitting their bid).

[21] The main difference between IBR and ID lies in the different iteration starting points. IBR starts the reasoning process from 50, whilst ID from 100. People in both groups iterate to different (level-n) degrees (Bosch-Domenech, Montalvo, Nagel, & Satorra, 2002). Nagel (1995) also concluded that IBR was the best description of the decision-making processes of individuals amongst those analyzed.

[22] "Some economists have argued that phenomena that appear irrational could be the result of rational players expecting others to behave irrationally" (Bosch-Domenech, Montalvo, Nagel, & Satorra, 2002). Conversely in this situation; those appearing rational by choosing the Nash Equilibrium incorrectly expect others to reason identical manner. This is known as a "false consensus" in psychology.

THE SELF-DISPLACING PROPHECY AS A BEAUTY CONTEST

The self-displacing prophecy can be likened to a p-mean beauty contest with p>1, but with some important differences. The mean is common knowledge; while "p" is not. In the original description of the game players supposedly know where the average is in order to tip above it. Furthermore, what "p" is varies from person to person. An interpretation of players tipping above the mean and having different expectations about how much other people tip above the mean is that "p" takes different values for different people: it can be 101/100 for someone and 102/100 for someone else. And in the simulated version players cannot "learn" to adapt their strategy.

AN ADJUSTMENT

To test the hypothesis that restricting information increases the time it takes for the equilibrium to be reached, I will relax the assumption that the average is common knowledge. I will therefore create a computational model that deals with local as well as global interaction. Assuming that information is only passed via interaction, then the model also becomes one where information is only locally available.

The agent-based modeling software 'Netlogo' will be used for testing, as "Agent-based models are especially powerful in representing spatially distributed systems of heterogeneous autonomous actors with bounded information and computing capacity who interact locally" (Epstein, 2006, p. 6).

SECTION 4: LOCAL INTERACTION

"The description of economic interaction is a key feature of many economic phenomena" (Blume, 1993). "The structure of a socioeconomic system can be considered as a complex network of interacting agents. While the direct interaction between agents is confined to a small subset of the population, all agents are indirectly connected through the network." (Berninghaus & Schwalbe, 1996). The relevance of social interactions has been increasingly recognized by economists, as they can help explain striking shifts in aggregate outcomes over time and space (Glaeser & Scheinkman, Measuring Social Interactions, 2001).

"Social interactions refer to situations where individuals are directly influenced by the choices of others" (Bramoulle, 2007). They can be positive, as when an action incentivizes more of the same action or negative, as when agents have an incentive to differ from what others are doing (Bramoulle, 2007). Similarly, they imply the presence of both positive and negative externalities. Glaeser and Scheinkman (2001) divide the mechanisms through which social interactions happen into four categories: physical, learning, stigma and taste-related.

"One controversy in the literature is whether social interactions are best thought as being local or global" (Glaeser & Scheinkman, 2000, p. 2). Local interaction occurs across neighbors, while global interaction through an aggregate (Glaeser & Scheinkman, 2001). Therefore, in models with global interaction, every agent presumedly interacts with all other agents. While in local interaction models interaction is limited; agents interact with only a subgroup of the general population (Babutsidze & Cowan, 2014). Global interactions usually result in more ordered systems, while local interaction usually produces richer and more complex dynamics (Babutsidze & Cowan, 2014).

Local interaction is also referred to as "neighborhood effect" in the economics literature. Not surprisingly, it (and local information) is implemented in agent based models by defining a local neighborhood.

SECTION 5: AGENT BASED MODELS

Agent based models (ABMs) are models of artificial societies used to study how macro-phenomena is generated by micro-specifications. ABM follows an evolutionary approach. They are computational tools used in many disciplines to study complex dynamics and phenomena: such as the spread of epidemics, demographic histories and the evolution of norms. "ABM looks at a system not at the aggregate level, but at the level of its constituent units" (Bonabeau, 2002).

Characteristic features of such models include: heterogeneity, autonomy, explicit space, local interactions, bounded rationality and non-equilibrium dynamics. According to Epstein (2006), their main contribution is to "facilitate generative explanation".

The generative approach tries to explain macroscopic regularity by showing how it could arise in a plausible society; with a set of heterogeneous, autonomous, boundedly rational and locally interacting agents. The generativist is concerned with formation dynamics. He wants to know how the equilibrium is reached.

AGENT-BASED COMPUTATIONAL ECONOMICS (ACE)

The target of computational models is to represent or simulate some real, existing phenomena (Gilbert, 2008). In this context, the model should be seen as a tool to better understand behavior, instead of a prediction tool.

Agent-based models are not new to the social sciences. They are used to study social dynamics and emergent macroscopic patterns. In Economics, Agent-based Computational Economics (ACE) is the term used to refer to the computational study of economic processes modeled as dynamic systems of interacting agents (Epstein, 2006). It allows us to relax some core assumptions in economics, to test the sensitivity of theories and to explore emergent phenomena (Epstein, 2006). Examples of its use in economics include stock market pricing strategies, trade networks, alliances and cooperation in spatial games. Schelling's segregation model (1971) is a pioneering example of its use in the field[23].

[23] Although Schelling did not use a computer.

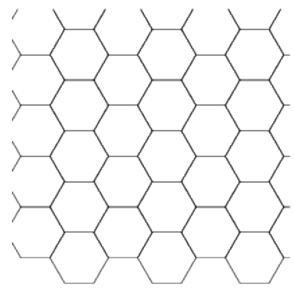
SECTION 6: A COMPUTATIONAL MODEL SIMULATING THE PROPHECY

For clarity and illustrative purposes, I will use Schelling's own 'tips' example to simulate the self-displacing prophecy.

GENERAL CHARACTERISTICS

Topology and Time

Figure 1: Hex Board



Players live on a torus. Each player is represented by a hexagon, such that the board structurally resembles a hexagonal lattice (see figure 1). As a tridimensional structure, it would closely resemble a Buckminsterfullerene[24] (without the pentagons). Each player has 6 neighbors, and neighbors share an equal amount of common neighbors throughout the board. The neighborhood is irrelevant in the simulation of the original model since interaction is global. When local interaction is present, agents interact only with their 6 closest neighbors (r=1). Furthermore, both learning and interaction neighborhoods are the same, and the neighborhood is fixed. Players update synchronously; all players make simultaneous decisions at all times. Time is accounted by discrete 'ticks' of the clock.

Variations

The self-displacing prophecy includes two variations. In the first version of the model, players are unaware of the game and do not act strategically. In the second variation, players myopically correct for others behaviors by increasing the amount of the tip. The two versions of the model are simulated with both global and local interaction, such that the tests cover 4 variations in total.

[24] A spherical chemical structure composed of 60 carbon atoms forming hexagonal and pentagonal shapes.

Initial Arrangement and Dynamics

There is a set of 255 goal-oriented agents (turtles) endowed with a random number ranging from 0 to 100. Numbers are randomly distributed across the board and represent how much agents would be willing to tip at the outset. At the tick of the clock, agents simultaneously take account and compare the mean tip (be it global or local) with their current tip. Agents do not change the amount tipped if it is higher than the mean. If it is smaller, agents re-evaluate how much above the average they would like to tip. Players tip simultaneously, and the game ends when all tips hit the ceiling.

There are slight differences between the four variations. The overall mean is common knowledge in the global interaction game. In the local interaction game people observe their neighbors to infer where the mean is. Furthermore, Agents tip different above average amounts, and make different corrections of the mean in the second version of the game.

Simulation Tests

Tests were run on BehaviorSpace, an extension of Netlogo specifically designed for that purpose. The computational model code can be found in the appendix. The model was run 1000 times for each version, and the results were then analyzed using SPSS. The following abbreviations were used for the statistical tests:

Table 1 – Simulation Labels

	Global Interaction	Local Interaction	Global and Local
1st Version	S1	L1	SL1
2nd Version	S2	L2	SL2

SECTION 7: SIMULATION RESULTS

From a first glance it is already easy to see that, as expected, it takes significantly less time for the game to end when people adjust for the behavior of other individuals. The statistical results show that it takes on average 32 and 19 plays for the first and second versions of the game to end (for all players tip the highest amount possible). The table below shows the mean times of the two versions of the prophecy with and without local interaction, as well as the mean times of their runs combined. In total, four variants were run: 'S1', 'S2', 'L1' and 'L2'[25] (see table 1 – simulation labels). Results of each version (1 and 2; which correspond to 'SL1' and 'SL2') were combined under the labels 'SL' for statistical analysis. Supplementary descriptive statistics are included in the appendix.

Mean "ticks"

Prophecy versions	S1	L1	SL1	S2	L2	SL2
Mean	32.90	31.45	32.18	19.98	18.47	19.22

It is less clear whether introducing local interaction into the game significantly alters the time it takes it to reach the equilibrium. The difference in mean time of the model with and without local interaction seems trivial (compare S1 with L1 and S2 with L2). Therefore I employed two identical procedures, one for each version of the model, to test whether the mean time changes when I introduce local interaction into the model[26]. I combined the necessary data under labels 'SL' to run the tests, and conducted two independent samples t-tests. Samples are large enough, there are no extreme outliers and the data distribution is approximately normal (see boxplots in the appendix). Both tests required I use independent variances and resulted in a p-value of 0. Therefore I have to reject the null hypothesis that the means are equal. Introducing local interaction significantly alters the mean time of the model versions. Full test results are included in the appendix.

[25] The labels identify the results obtained for each simulated variant of the prophecy. 'S' stands for Schelling and 'L' for local interaction. The numbers make reference to versions of the prophecy.

[26] The tests are used to compare the mean times of the model with and without local interaction. Each procedure corresponds to a version. Therefore the 'SL1' combined data is used to test the time difference after introducing local interaction in model version 1.

The tests are enough evidence of a time difference since I have a big enough sample and the data has no extreme outliers. However, simulation results of both model versions with local interaction showed that although there are no extreme outliers, there are at least some moderate ones present. To verify that the previous test results were not a product of the outliers, additional Wilcoxon Rank Sum tests[27] were taken for both procedures. Both tests also reported a p-value of 0. Therefore in this instance I also reject the null hypothesis that the distribution of times is the same. I can only conclude that the second version of the prophecy converges faster than the first to the upper boundary, and that introducing local interaction significantly alters the mean time it takes for both to reach the equilibrium.

[27] SPSS uses the Mann-Whitney Test instead. The two tests are equivalent; they report the same p-value.

SECTION 8: CONCLUSION

The self-displacing prophecy, by name, has rarely been mentioned in the literature. But proxy games and models, such as the p-beauty contest, have been thoroughly researched. In this paper I tested whether the self-fulfilling prophecy has a significantly lower speed of convergence towards the upper boundary when there is restricted information about the average. Statistical tests conducted on the simulation results suggest that there is a significant difference in the time it takes for the mean to reach the Nash equilibrium when information is local. Expectations of behavior also alter considerably the rate of convergence. It remains to be seen whether the mean can be halted at a lower boundary when individuals are expected to be more sophisticated and different learning model mechanisms are used.

If the empirical research conducted on such games is any indication of the prophecy workings in real life, then there is room to believe that there are some instances in which the prophecy would break down. In any case, it can still be said that it would relatively take a long time for the equilibrium to be reached in real life. And longer still when access to information about averages is restricted. If the game is anything similar to the previously argued example about the SATs, where each person only gets to take it once, then the change could span generations.

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APPENDIX

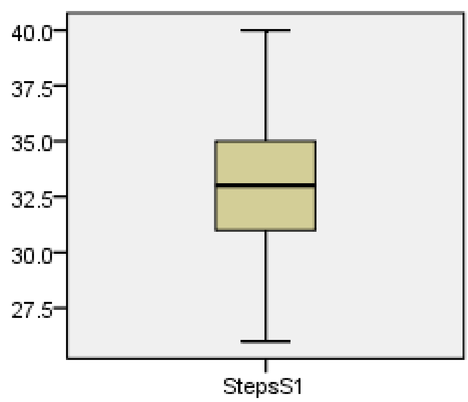
Statistical Analysis

Descriptive Results

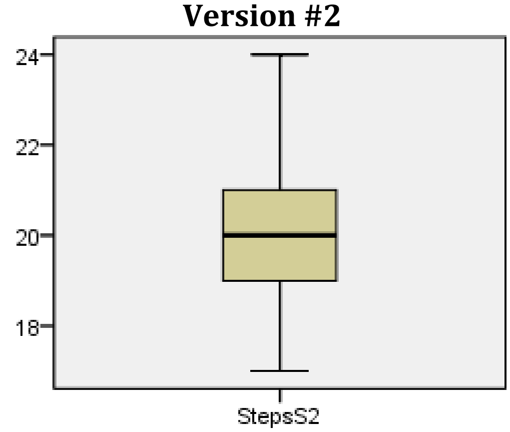
Frequencies

	StepsS1	StepsL1	SL1	StepsS2	StepsL2	SL2
Mean	32.90	31.45	32.18	19.98	18.47	19.22
Median	33.00	31.00	32.00	20.00	18.00	19.00
Mode	33	32	33	20	19	20
Minimum	26	18	18	17	10	10
Maximum	40	48	48	24	27	27

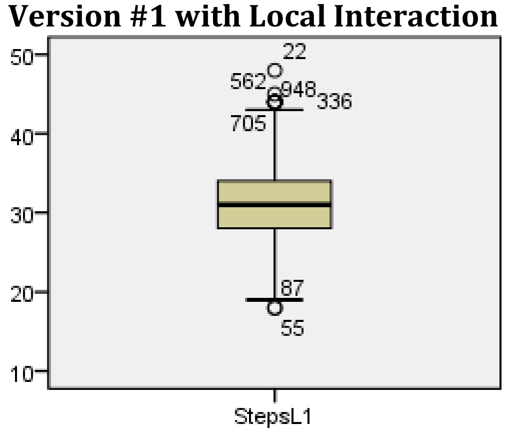
Version #1



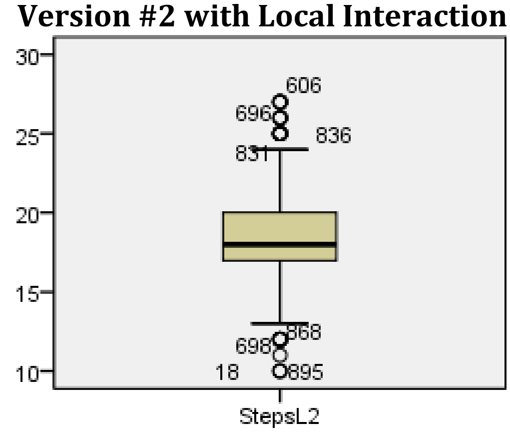
Version #2



Version #1 with Local Interaction



Version #2 with Local Interaction



Test Results

T-Test – Version #1

Group Statistics

	Groups	N	Mean	Std. Deviation	Std. Error Mean
SL1	1	1000	32.90	2.539	.080
	0	1000	31.45	4.564	.144

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SL1	Equal variances assumed	258.595	.000	8.743	1998	.000	1.444	.165	1.120	1.768
	Equal variances not assumed			8.743	1563.392	.000	1.444	.165	1.120	1.768

T-Test - Version #2

Group Statistics

	Groups	N	Mean	Std. Deviation	Std. Error Mean
SL2	1	1000	19.98	1.263	.040
	0	1000	18.47	2.776	.088

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SL2	Equal variances assumed	442.769	.000	15.667	1998	.000	1.511	.096	1.322	1.700
	Equal variances not assumed			15.667	1395.556	.000	1.511	.096	1.322	1.700

Mann-Whitney Test – Version #1

Ranks

	Groups	N	Mean Rank	Sum of Ranks
	0	1000	888.76	888758.00
SL1	1	1000	1112.24	1112242.00

Test Statistics[a]

	SL1
Mann-Whitney U	388258.000
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Groups

Mann-Whitney Test – Version #2

Ranks

	Groups	N	Mean Rank	Sum of Ranks
	0	1000	805.50	805496.50
SL2	1	1000	1195.50	1195503.50

Test Statistics[a]

	SL2
Mann-Whitney U	304996.500
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Groups

Netlogo Model Code

```
globals [ initial-mean global-mean
        initial-value-origin initial-local-mean-origin value-origin local-mean-origin local-mean hex-means-list ]
turtles-own [ value
           expected-value
           mean-local-value
           hex-neighbors ;; agentset of 6 neighboring cells
           n ]

;;-----------------------------------------------------
;; ------------------- SETUP -------------------------
;; ------------- SCHELLINGS BUTTON --------------------
;;-----------------------------------------------------

to setup1
 clear-all
 setup-grid
 setup-initial-values
 setup-initial-turtles
 initial-setup-checker
 reset-ticks
end

to setup-grid                          ;; Board/grid setup
 set-default-shape turtles "hex"
 ask patches
   [ sprout 1
          [ set label value
            set label-color white
            if pxcor mod 2 = 0 [ set ycor ycor - 0.5 ]]] ;; Shifts even columns down
 ask turtles ;; Setting up the hex/turtle-neighborhood
  [ ifelse pxcor mod 2 = 0
     [ set hex-neighbors turtles-on patches at-points [[0 1] [1 0] [1 -1] [0 -1] [-1 -1] [-1 0]]]
     [ set hex-neighbors turtles-on patches at-points [[0 1] [1 1] [1  0] [0 -1] [-1  0] [-1 1]]]]
end

to setup-initial-values                    ;;whether initial mean value is random or turtles defined
 ifelse random-initial-mean?
 [set initial-mean random-float endowment-ceiling ]
 [set initial-mean global-mean]
end

to setup-initial-turtles                ;; Setup of the initial value of turtles
 ask turtles [ ifelse random-initial-mean?
  [set value initial-mean]
  [set value random-float endownment-ceiling ]]
 set global-mean mean [value] of turtles
 set initial-mean global-mean
 number-value
 recolor
end

to number-value                          ;; if numbers should be shown
 ask turtles [set label precision value 2 ]
```

```
end

to recolor                          ;; color attributes
  ask turtles [ set color scale-color red label endownment-ceiling 0 ]
end

to-report hex-means
  report mean [value] of hex-neighbors
end

;; Checking if local interaction calculation has been done correctly
to initial-setup-checker
  ask patch 0 0 [ask turtles-here [ set initial-value-origin value ]]
  ask patch 0 0 [ask turtles-here [ set initial-local-mean-origin mean [value] of hex-neighbors]]
  set value-origin initial-value-origin
  set local-mean-origin initial-local-mean-origin
  set hex-means-list ([ hex-means ] of turtles)
end

;;-------------------------------------------------
;;--------------------- ACTION ---------------------
;;-------------------------------------------------

;;-------------------------------------------------
;; ------------- Situation #1 ----------------------
;;--------------------------------------------------
;; People tip above average

;;-------------------------------------------------
;; --------------- Schelling -----------------------
;;-------------------------------------------------

to go1.1
  normal-bhv
  setup-connector
  tick
end

;; Same as above, but ticks continuously
to go1.1.1
  if mean [value] of turtles = upper-limit [ stop ]
  normal-bhv
  setup-connector
  tick
end

to normal-bhv
  let mean-value mean [value] of turtles
  ask turtles [ if value <= mean-value [ set value mean-value + random-float Tip ]]
  ask turtles [ if value >= upper-limit [ set value upper-limit ]]
  number-value
  recolor
end

to setup-connector
```

```
  ask patch 0 0 [ask turtles-here [ set value-origin value ]]
  ask turtles [set local-mean-origin mean [value] of turtles ]
end

;;---------------------------------------------------
;; ------------- With Local Interaction --------------
;;---------------------------------------------------

to go1.2
  normal-local-bhv
  setup-checker
  tick
end

;; Same as above, but ticks continuously
to go1.2.1
  if mean [value] of turtles = upper-limit [ stop ]
  normal-local-bhv
  setup-checker
  tick
end

to normal-local-bhv
  ask turtles [ set local-mean mean [value] of hex-neighbors ]
  ask turtles [ if value <= local-mean [ set value local-mean + random-float Tip ]]
  ask turtles [ if value >= upper-limit [ set value upper-limit ]]
  number-value
  recolor
end

to setup-checker
  ask patch 0 0 [ask turtles-here [ set value-origin value ]]
  ask patch 0 0 [ask turtles-here [ set local-mean-origin mean [value] of hex-neighbors]]
  set hex-means-list ([ hex-means ] of turtles)
end

;;-----------------------------------------------------
;;-------------------- Situation #2 --------------------
;;-----------------------------------------------------
;; Myopic Beliefs/Expectations of Behavior
;; Myopic correction of the average
;; People myopically adjust behavior to correct for others behavior

;;------------------------------------------------------
;;------------------Situation #2.1-----------------------
;;-----------------Equal Correction----------------------
;;------------------------------------------------------

;; Here people make the same correction:
;; People have the same expectation about people's correction
;; Everybody has the same expectation about the new average (where it is)

;;------------------------------------------------------
;;-----------------Schelling----------------------------
;;------------------------------------------------------
```

```
to go2.1
  same-correction
  setup-connector
  tick
end

;; Same as above, but continuous
to go2.1.1
  if mean [value] of turtles = upper-limit [ stop ]
  same-correction
  setup-connector
  tick
end

to same-correction
  let mean-value mean [value] of turtles + random-float Tip
  ask turtles [ if value <= mean-value [ set value mean-value + random-float Tip ]]
  ask turtles [ if value >= upper-limit [ set value upper-limit ]]
  number-value
  recolor
end

;;------------------------------------------------------
;;------------------Local Interaction--------------------
;;------------------------------------------------------

 to go2.2
  same-local-correction
  setup-checker
  tick
end

;; Same as above, but continuous
to go2.2.1
  if mean [value] of turtles = upper-limit [ stop ]
  same-local-correction
  setup-checker
  tick
end

to same-local-correction
  let same-correction-mean random-float Tip
  ask turtles [ set local-mean ((mean [value] of hex-neighbors) + same-correction-mean) ]
  ask turtles [ if value <= local-mean [ set value local-mean + random-float Tip ]]
  ask turtles [ if value >= upper-limit [ set value upper-limit ]]
  number-value
  recolor
end

;;------------------------------------------------------
;;--------------------Situation #2.2---------------------
;;----------------Different Corrections------------------
;;------------------------------------------------------
;; Here people make different corrections
```

```
;; Different expectations of where the new average lies

;;-----------------------------------------------------
;;------------------Schelling--------------------------
;;-----------------------------------------------------

to go3.1
 diff-correction
 setup-connector
 tick
end

;; continuous ticks
to go3.1.1
 if mean [value] of turtles = upper-limit [ stop ]
 diff-correction
 setup-connector
 tick
end

to diff-correction
 let mean-value mean [value] of turtles
 ask turtles [ set expected-value mean-value + random-float Tip ]
 ask turtles [ if value <= expected-value [ set value expected-value + random-float Tip]]
 ask turtles [ if value >= upper-limit [ set value upper-limit ]]
 number-value
 recolor
end

;;-----------------------------------------------------
;;------------------Local Interaction--------------
;;-----------------------------------------------------

 to go3.2
 diff-local-correction
 setup-checker
 tick
end

;; Same as above, but continuous
to go3.2.1
 if mean [value] of turtles = upper-limit [ stop ]
 diff-local-correction
 setup-checker
 tick
end

to diff-local-correction
 ask turtles [ set local-mean ((mean [value] of hex-neighbors) + random-float Tip) ]
 ask turtles [ if value <= local-mean [ set value local-mean + random-float Tip ]]
 ask turtles [ if value >= upper-limit [ set value upper-limit ]]
 number-value
 recolor
end
```