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Keywords
Agent-Based Model, Ponzi Schemes, NetLogo

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C63, K42, G11, D83

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Illusions and Perceived Wealth: an Agent-based model of Madoff's Ponzi scheme

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Keywords: Agent-Based Model · Ponzi Schemes · NetLogo.

1 Introduction

Ponzi schemes are infamous scams where, loosely speaking, returns are paid to old investors using the flows coming from newly enrolled investors. This definition has gained some popularity and captures, perhaps, one of the most salient features of the first scheme run by Charles Ponzi in the 1920's.

However, a clear and shared definition of similar scams is, to the best of our knowledge, not present in the literature or in the popular press where "Ponzi scheme" is often akin to an umbrella term for financial scam, including for instance the Madoff's gigantic fraud that, we will argue, has a different structure.

In this paper, we will use the term Ponzi scheme for a very common financial hoax where

1. the funds of the investors are, actually, not invested at all;
2. the investors *believe* they money is steadily increasing at unrealistic rates with no or little risk. Essentially, they are believers;
3. the swindler uses the (residual) true flows for his own expenditures, as well as for repaying the investors who liquidate their position, till this is possible.

Bernie Madoff is widely credited to have run the largest Ponzi scheme in history, defrauding customers of about 65 billion dollars. However, in all evidence, he could pay back for many years all the investors who reclaimed their principal and interests. This was not necessarily done by using fresh inflows but just eroding some pool of accumulated wealth that was mostly raised in the first years of his enterprise.

We will use Madoff's scam to guide our exposition and agent-based modeling exercise. He began is financial activity in 1960, [1], running a brokerage firm that grew into Bernard L. Madoff Investment Securities. It is not entirely clear when the scam began, probably in the early 1990s, but the lie surfaced only on 10 December 2008. In a guilty plea to eleven federal offenses on March 12, 2009, Madoff acknowledged transforming his wealth management company into a vast Ponzi scam[1]. Our preferred book on the topic is [6], and [2] is a recent review of the topic. Other good accounts are [4], [3] and [8]. An overwhelming amount of data and documents on the fraud can be found on the websites of the "Madoff Victim Fund" (https://madoffvictimfund.com/, a Department of Justice asset forfeiture distribution program), "The Madoff Recovery Initiative" (https://www.madofftrustee.com/, well known for the efforts of the trustee Irving Picard), and the U.S. Securitiues and Exchange Commission (https://www.sec.gov/, even though nerws are scattered and somewhat difficult to retrieve).

Madoff's fraud is widely believed to have crumbled in the aftermath of the global financial turmoil of 2008. A crisis of trust in

[1] Madoff was condemned to a 150-year prison sentence and died, aged 82, in 2021.

financial institutions' capacity to fulfill their obligations, triggered by the failures of major players, including commercial banks, securities broker-dealers, and insurance, spurred a number of investors to retreat from any risky position. In brief, Madoff couldn't survive the flood of requests by his customers and the scam was revealed, [8].

We stress that early allegations of wrongdoing by Madoff's were raised, with no consequences. In particular, we focus on the work by Harry Markopolos, who claimed his hedge fund was a fraud since 1999 when he listed, in a complaint to the SEC, 29 *red flags* or reasons to believe that the returns were fabricated. The accusations were basically ignored and buried in the archives, just to be shamefully re-discovered when it was too late.

Inspired by the previous description, we model the case based on three main assumptions. Firstly, agents initially have a positive propensity to invest money believing that their return will be, say, 1% a month, with negligible or no risk. Investors are not going to redeem their investment in one or two months (and indeed many of the persons or organizations involved in Madoff's bloodbath stayed invested for years, if not decades). Leaving the money invested in the assets managed by the swindler is seemingly a very good deal, as they believe it will further grow at the inflated rate. In other words, their perceived wealth is growing in their mind based on false formal records or fake informal accounts or just laziness and inertia.

Secondly, mimicking the general loss of confidence that occurred in 2008, we assume that bad news and a negative mood spread gradually in the market, with a variable intensity, and is absorbed by agents. This mood reduces the propensity to invest in the first instance, and push agents to disinvest at some point.

Thirdly, we examine the effects of a Markopolos-type of agent assuming, in one parametrization, that there is one trader capable of spreading the news that a scam is in place. This is done allowing agent Markopolos to make the sentiment of the agents that were met to very negative values. Hence, Markopolos effectively, but occasionally, convinces others to disinvest quickly from the Madoff's business.

The paper is organized as follows. In the next Section, the model is described using the ODD protocol that outlines an overview of the model, illustrates its design, and provides the details. Section

3.2 presents a representative run of the model and displays simulation results, analyzing the impact of the changes in the values of key parameters. The final Section discusses the economic and policy implications of the results and concludes the work.

2 The mdoel (ODD description)

We describe in the following the model using the Overview, Design, (ODD) protocol, described in [5].

2.1 Purpose

The model aims at showing that Ponzi schemes can be generated by a process in which an illusory growing wealth is perceived (by investors), whereas the real capital under management (by the impostor) is declining. This process of systematic double accounting is a key driver of most, if not all, fraudulent schemes.

2.2 Entities, state variables and scales

State variables are in italics in what follows. The model features investors, a unique impostor and, in one version, a special agent (named Markopolos) who can reveal the scam. Investors and Markopolos move on a toroidal grid of patches endowed with some level of bad *mood*. The impostor "doesn't move" and can be thought as an abstract mastermind, getting monies from investors and consuming a part of it for its own reasons in every period.

Investors own *cash* and *perceived.wealth*. While the *cash* is kept and retains its value, the *perceived.wealth* is the fictitious wealth of the investor, believed to grow at favourable rate and in the hands of the impostor. The extent to which investors are willing to transfer *cash* to the impostor, with the ultimate goal to get rich is depending on their *sentiment*. A positive (negative) *sentiment* is correlated with a positive probability to transfer (reclaim) money to (from) the impostor.

The impostor owns *total*, that is the sum of true money still in his control at any given time. This *total* depends on the inflows by investors, who believed their wealth would grow at monthly constant rate $r > 0$, and by the outflows of the ones who redeem all or a part of what was invested. Also, *total*, due to hidden expenses or withdrawals by the impostor, decreases at monthly rate r.

The special agent named Markopolos is simply an investor who never invests, and has the power to convince investors to reclaim some of or all their *perceived.wealth*. In other words, Markopolos can turn the *sentiment* of the ones who are met to very negative values, pushing them to disinvest.

The *mood*, covered more deeply in the following section, is a variable of the spatial cells and it is deducted from the *sentiment* of the investors who are in that cell. Hence, *mood* reduces the probability to invest in the scheme, as well as triggering reclaims if it pushes *sentiment* into negative territory.

The tick of the model can be thought as of one month.

2.3 Process overview and scheduling

At the beginning of every tick, agents compute the probability to give a fraction of their *cash* to the impostor or to withdraw some of their *perceived.wealth* from him. This probability is a function of the *sentiment*. The amount involved can be described by a uniform random variable distributed over the interval between zero and *perceived.wealth*, if it is a redemption, or between zero and *cash*, if it is an investment. Hence, on average, investors give half of their *cash* or reclaim half of their *perceived.wealth*.

The impostor collects the *cash* and pays the reclaims, if this is possible, i.e., if `total` plus all the cash received less the reclaimed sums is positive; else, there is a bankruptcy, the scam is revealed to everyone and the simulation stops.

Every tick, a quantity *diff* of *mood* is deposited on a random cell. Moreover, all cells spread 50% of their mood on the 8 neighbors. This mimics the arrival of bad news in the market and the slow diffusion of the news in the space.

If Markopolos is active in the model, in the presence of a random meeting with another agent, the latter changes his/her *sentiment* to a very negative value. This fact can be interpreted as a revelation that the investment is based on a scam and, as a consequence, the investor will reclaim his *perceived.wealth* in the future ticks.

At the end of every tick, *total* decreases to $total(1-r)$, and the *perceived.wealth* of all investors increases to $perceived.wealth(1+r)$. Let us notice again that this is sham money, in the head of investors but no longer owned by the impostor, even though he usually provides false statements asserting the opposite. All investors update their *sentiment* taking away the *mood* of the cell they are located.

2.4 Design

Basic principles:

- the fraud is built and survives because of the "double" accounting happening among agents, who think their investments steadily grow, whereas their wealth managed by the impostor steadily shrinks;
- based on the sign of *sentiment*, there is a positive/negative probability to invest in the scam or disinvest;
- the *sentiment* of the agents decreases if they transit on cells with (bad) mood.

Emergence: as bankruptcy is expected, due to the general decrement in *sentiment* fuelling disinvestments that will ultimately lead the impostor's balance to 0, among the most interesting features generated by the model there is the existence of *sentiment* threshold at which losses abruptly change. Additionally, the role of Markopolos appears to have, at first, little aggregate impact, even though subtle effects largely affect a small set of agents.
Adaptation: agents update their initial positive *sentiment* by deducting the mood or meeting the special agent Markopolos.
Objectives: broadly speaking agents want to maximize their profit and, therefore, initially have a positive propensity to invest and reap large returns.
Learning: it takes place when agents met Markopolos ("revealing" the scam and pushing them to disinvest). Also, the stygmergic process of subtracting *mood* from the *sentiment* is akin to the slow absorption of bad news on the economy at large or on the trustworthiness of the scheme.
Prediction: not relevant in the model.
Sensing: agents sense the *mood* in their location and use it to reduce their *sentiment*.

Interaction:

- agents interact with the space absorbing the *mood* (in this sense, the patches are places where news are stored, diffused, found and digested);
- the encounter with Markopolos affects the *sentiment* and can spur immediate disinvestment.

Stochasticity: there are various random elements in the model.

- the probability (or, more colloquially, the propensity) of investing/disinvesting is a function of the *sentiment*:

$$Prob(invest) = \sigma(sentiment), \quad \text{if } sentiment > 0;$$
$$Prob(disinvest) = \sigma(sentiment), \quad \text{if } sentiment \leq 0,$$

  where

$$\sigma(x) = 1/(1 + \exp(-2|x|)),$$

  (the function is depicted in Figure 1).

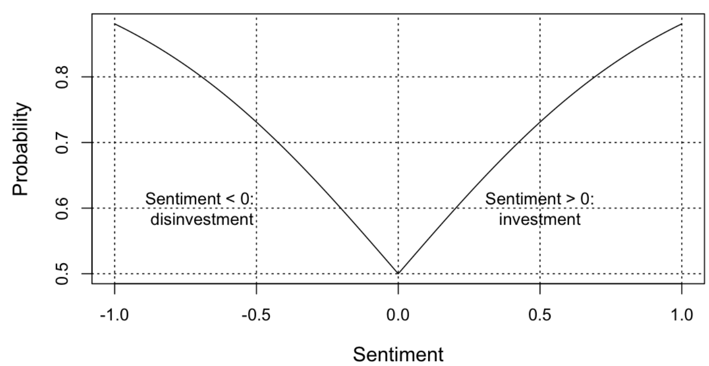

Fig. 1. The probability of acting as a function of the *propensity*. If the *propensity* is positive (negative), the agent invest (disinvest) a random fraction of his *cash* (*perceived.wealth*).

- The amounts that are invested, $\tilde{U} \cdot cash$, or disinvested, $\tilde{U} \cdot perceived.wealth$, are random amounts contingent on the draw from a standard uniform variable $\tilde{U}[0, 1]$;

- Agents move randomly in the space and, hence, randomly collect *mood* to be deducted from *sentiment*;
- the special agent Markopolos randomly moves and meets other agents.

Collectives: not relevant in this paper.
Observables: in this work we focus on

- the number of ticks needed, with various instantiations of the parameters, to reach bankruptcy (this is the time needed to reveal the scam);
- the total loss generated by the scam;
- the effects of the Markopolos agent;
- the distribution of the losses/gains among the population of agents.

2.5 Initialization

We initialize $N = 150$ agents, setting *cash*= 1 at the beginning of the simulation. The propensity is initially set at $\tilde{U}$. We assume that $r = 0.01$, i.e., the scammer consumes 1% of his wealth per period while agents trust their "savings" grow at 1% per period.

2.6 Input data

The model does not use external data.

2.7 Submodels

We provide the description of two modules, namely the very simple one in charge to move the turtles and the one managing the the encounters with the special agent Markopolos. The model was coded using Netlogo, [10].

```
to wander-move
  ;; Turn left or right by a small, random angle
  ;; up to 'turn-variance'
  rt random-float turn-variance
  lt random-float turn-variance
  forward d
end
```

In the simulations, `turn-variance` is 20. It remains to be investigated whether changes in `turn-variance` alter the results.

```
to Markopolos
  ;; Look for other turtles on the same patch
  ;; (excluding itself)
  ask turtle 0 [
    let companions other turtles-here
    if any? companions [
      let s [sentiment] of turtle 0
      ask target [set sentiment s]
    ]
  ]
end
```

The previous code ask Markopolos (turtle 0) to select one target agent among the companions, if any, sharing its own location (patch). Then the target copies the very negative sentiment of Markopolos (a sentiment of -5, used in the code, generates a probability to disinvest equal to 0.999955).

2.8 Discussion

We elaborate her one some key features of the model previously described using the ODD protocol.

The agents are born with positive propensity and initially are prone to invest in the not-yet-revealed scam. They are going to change their behavior, moving from investment to disinvestment, as soon as their propensity becomes negative along time. This can happen for two reasons: either news conveying (bad) mood pop up in the world, spread and are slowly absorbed; or they meet the special agent Markopolos (when he is present, he will be given the honor to be turtle 0!) who suddenly changes their propensity to very negative values that triggers rapid-fire disinvestments.

The other character in the plot is the scammer, who collect cash from agents, fails to truly invest on their behalf, squanders for personal reasons 1% per period and let all others believe that, instead, the funds are growing at the same rate (for simplicity).

It may be useful to point out some subjective (indeed, arbitrary) choices we made in designing the model. There is no solid reason to assume[2] that $r = 0.01$ and we vastly use standard uniform random values for the lack of clearly better options. Hence, agents invest/disinvest on average 50% of their true cash or perceived wealth. They also have initial propensities in $[0, 1]$ meaning that initially they on average will invest with a probability ranging from 50 to almost 90% (per period). When their propensities switch from a small $\epsilon > 0$ to $-\epsilon$, they move from being (skeptical) investors with probability 50% to (equally skeptical) dis-investors with the same chance.

A look at the module *Markopolos* discloses that little changes may fan the flames of large consequences. Replacing the line `ask turtle 0 [` with `ask turtles with [sentiment <= -5][` would allow the agents who were "converted" by Markopolos to convert others in subsequent periods, triggering a cascade that is likely to accelerate the collapse of the scheme. Moreover, while we assumed that only a single `target` at a time can be alerted by Markopolos, changing `ask target [set sentiment s]` into `ask companions [set sentiment s]` enables multiple sentiment revision in one tick.

3 Results

The parameters used in the model are summarized in Table 1.

Table 1. Parameters of the simulations

Number of agents	150 for each run
Coefficient of diffusion `diff`	from 0.05 to 1 by 0.05
Markopolos effect	true/false
collective effect	true/false
replications for each combination of parameters	10

We mainly focus on: the time needed to reveal the bankruptcy (i.e, the number of ticks needed to reduce to nil the amount in the hands of the scammer); the total loss incurred by agents; the role of Markopolos and the distribution of losses/gain of agents at the end-titles (before criminal investigations begin). In the next Subsection

[2] In several scams, however, advertised returns may have been of the same order. Madoff often claimed the returns were close to, or not exceeding much, 10% yearly.

we describe a representative simulation to provide the main gist of the model.

3.1 A representative run

In the benchmark case, the amount *diff* = 0.15 of news hitting the market is moderate and, as a consequence, the *sentiment* decreases rather slowly. Figure 2 shows the sum of *perceived.wealth* (in black) and the true amount (*total*, in red) in the scheme, as a function of time.

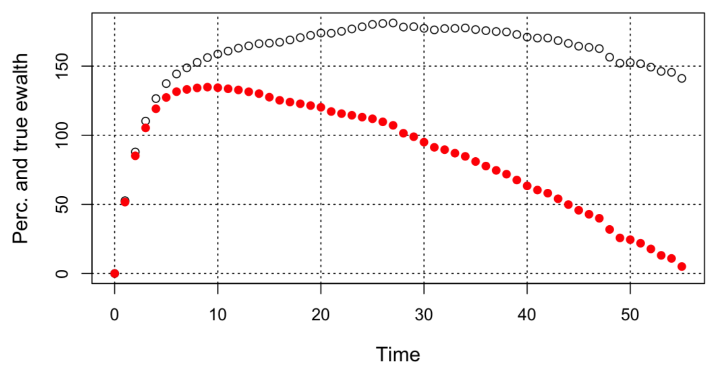

Fig. 2. Perceived wealth and the amount in the scheme.

In this simulation, bankruptcy is reached in 55 periods (months), see the red points. Initially, the inflows into the scheme are large and the sum available to the scammer peaks after 10 periods. The *perceived.wealth* continues to grow till the period 25, and then stabilizes while agents are investing and disinvesting at the same time. The structural insolvency of the scheme is already evident at $t = 10$ (the potential claims largely exceed the residual capital), but the gap between what is perceived (in the agents' minds) and what is factual (in the hands of the scammer) keeps widening. Observe that, despite the fact that many agent become aware of the situation and disinvest, agents still believe they possess 141.11 in total when the bankruptcy materializes.

Figure 3 displays the time-series of inflows (outflows) into (out of) the scheme. The rapid surge in investments is followed, after period 10, by a lack of further inflows (that are not "needed" by the scammer who already has full control over a large swath of money).

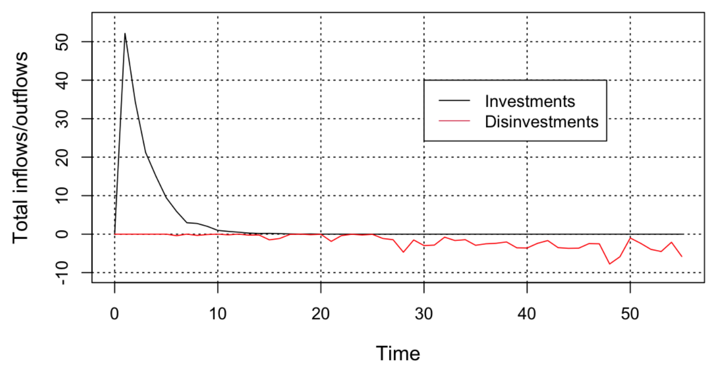

Fig. 3. Inflows / Outflows

Beginning in period 20, an increasing number of agents choose to disinvest, sometimes in considerable quantities (as indicated by the red line). This, combined with the 1% reduction per period of what is with the fraudster, will deplete his reserves, that are utilized to reimburse the agents who wish to disinvest.

To look at the outcome along a different perspective, the left panel of Figure 4 displays the wealth of the 150 agents at the end of the simulation (this is exactly *cash*), as a function of the initial *sentiment*. On the one hand, the agents with a large *sentiment* invested earlier and did not disinvest before the collapse, as more (negative) mood was to be gathered to slash their initial enthusiasm. Not surprisingly, they had not the time to pull back and their final wealth is zero (in detail, there were 71 such agents).

On the other hand, agents who had low starting sentiment did participate in the scam, but they were comparatively quick in absorbing enough negative mood to disinvest before the bankruptcy. The graph reveals an abrupt shift around (initial) $sentiment = 0.45$.

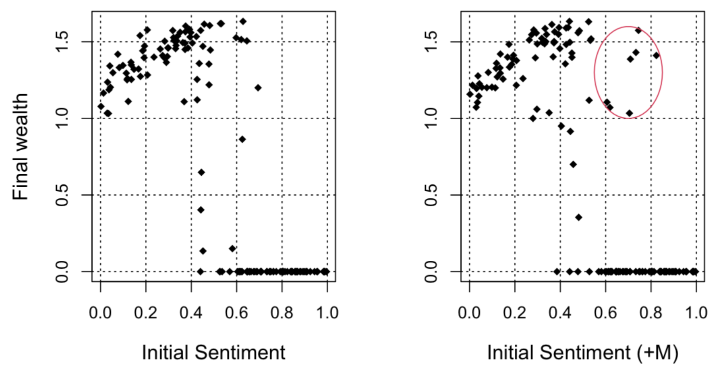

Fig. 4. Final wealth (at bankruptcy) of agents as a function of their initial sentiment in the absence (left panel) and in the presence (right panel) of Markopolos.

Although the precise value is difficult to interpret, the presence of a threshold captures the idea that a razor-thin margin separated the fortunate, who disinvested shortly before Armageddon, from the unfortunate, who did so slightly later[3]. To put it in another way, agents with nearly identical *sentiment* may have earned as much as 0.70 (beyond their initial endowment of 1), or they could have lost everything.

The right panel of Figure 4 shows, *ceteris paribus*, the effects of having Markopolos in action (the agents on the right have exactly the same *sentiment* of the ones on the left and the same seed was used to "align" the two cases; the simulation on the right lasted 55 periods and, again, exactly 71 agents have zero wealth at the end). The two pictures are very similar: agents with large (small) *sentiment* end up in opposite situations where they are likely to earn much (loose everything). We will discuss the role and the significance of the Markopolos agent later, but one interesting hallmark is that a handful of agents, emphasized by a red circle on the right panel, have sizable gains despite their large *sentiment*. A straightforward interpretation is that they are the (few and blessed) ones who met Markopolos and, having being alerted of the scam, swiftly escaped

[3] Actually, they didn't do anything because the game was over!

away (technically, this is obtained setting *sentiment* to very negative values and triggering a sequence of disinvestments).

The following Subsection explores systematically how results are affected by variations in key parameters.

3.2 Simulations

It is interesting to examine the dependence of the time needed to reach the bankruptcy on the *diff*, a proxy of the intensity of the flow of news deteriorating the sentiment. In Figure 5 points represent the mean number of *ticks* (periods) needed to reach bankruptcy. The vertical segments are the standard deviations (10 simulations for each point) and we displays three situations:

- no absorption of news[4], Markopolos is present (yellow);
- news are absorbed, no Markopolos (gray);
- news are absorbed and Markopolos is present (blue).

When no news is absorbed, the presence of Markopolos leads the scheme to failure in about 135 periods, see the yellow points. This span of time is independent of *diff*, subject to some random variability and quite long. The results can be interpreted as an indication that Markopolos alone has a mild effect on the collapse of the scheme.

If, instead, the news are absorbed and lead to the reduction of the sentiment, bankruptcy occurs much more rapidly as the volume of news reaching the market increases. For instance, low values of *diff* generate the collapse in 60-80 periods, whereas for large values bankruptcy occurs in as few as 20 periods (gray curve). The first situation corresponds to a very slow accumulation of negative mood in the populations of agents. An increase in *diff* is comparable to cases in which the pressure of the media is elevated and traders have many opportunities to review their sentiment downward, making withdrawals more and more frequent and likely.

The presence of Markopolos does not appear to change much the outcome, as the gray and blue curves almost overlap, even though some discrepancies can be seen in Figure 6, where we zoom in on the relevant portion of Figure 5.

[4] In other words, whatever the *diff*, agents' sentiment is changed only by an encounter with Markopolos.

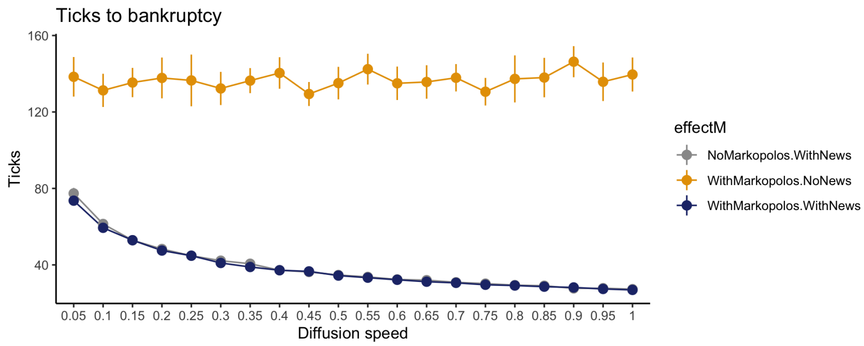

Fig. 5. Time to bankruptcy when no news is absorbed but Markopolos is present (yellow); news are absorbed, no Markopolos (gray); news are absorbed and Markopols is present (blue). We used 10 simulations per point and one standard deviation is depicted using vertical segments.

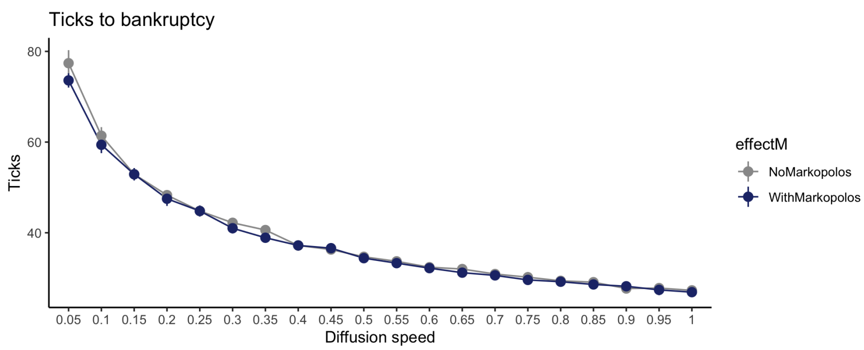

Fig. 6. Final ticks: comparisons

To investigate the extent to which Markopolos influences the results, we looked at the joint distribution of (initial) *sentiment* and (residual) *cash* at the time of bankruptcy. To this end, we run 10 simulated with/without Markopolos, with the same random seed and *diff* = 0.05. We obtained 1500 pairs (150×10) of outcomes (*sentiment,cash*) that can be used to compute a non-parametric kernel estimate of the joint distributions of the two variables under the two "treatments" with/without Markopolos. A comparison is shown in Figure 7: the two density are quite similar, as suggested by the nearly perfect superposition of Figure 6, but the effect of Markopolos (bottom panel) is visible, as opposed to his absence, in the dark "shoulder" extending to values of large (initial) *sentiment* and proving that there is (some little) probability for those agent to exit the game with positive *cash* and conspicuous gains. Interestingly, they are typically the ones in the circle depicted in Figure 4.

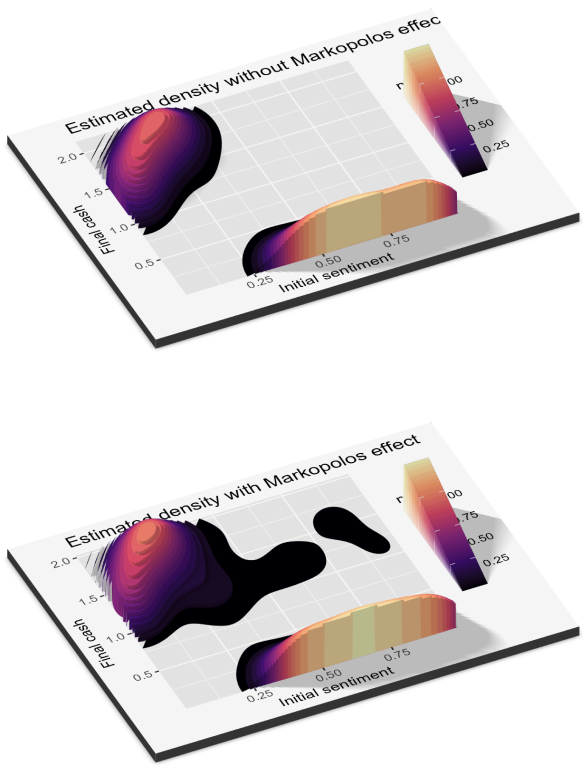

Fig. 7. Estimated densities of (sentiment,cahs) at bankruptcy: without Markopolos (top panel), with Markopolos (bottom) panel.

To formally check whether the difference in the two distributions is statistically significant, we apply Pearson's chi-square test of independence, comparing the aforementioned 1500 observations in each case. Tables 2 and 3 show the number of data-points in the bins corresponding to the terciles of the distribution (without Markopolos).

Table 2: Without Markopolos, *diff* = 0.05

	cash		
sentiment	0	(0,1.21]	(1.21,2.16]
(0,0.32]	1	37	461
(0.32,0.65]	136	325	39
(0.65,1]	362	137	0

Table 3: With Markopolos, *diff* = 0.05

	cash		
sentiment	0	(0,1.21]	(1.21,2.16]
(0,0.32]	1	77	409
(0.32,0.65]	94	352	64
(0.65,1]	271	191	39

The Pearson's chi-square strongly rejects the independence of the two different treatments, with p-value close to zero, leading to the conclusion that the presence of Markopolos agent is significant.

4 Conclusions

The paper presents a model of a Ponzi scheme using the Madoff's fraud as an archetype. In many similar scams, investors' money is not invested but kept by the fraudster, who (slowly) squanders it for personal use and to reimburse the customers reclaiming their capital and profits. Agents think (i.e., mistakenly believe) in gains and feel they are rich, owning a *perceived.wealth* that only exists in fabricated accounts or false documents. Akin to what possibly happened in the Maddoff's case, we model a general loss of trust in the markets where the initial propensity of agents to invest in the fraud is undermined by the absorption of (bad) news on the economy. We also investigated the effect of a special agent, named Markopolos, that can convince agents to withdraw from the scheme in a short time, effectively turning potential investors into "fugitives".

The model, developed in NetLogo, robustly shows the structural insolvency of the scheme, due to the widening gap existing between perceptions and the true *total* money left with ine scammer. Bankruptcy is revealed as soon as no money if left to satisfy the one who reclaim what they think is due. The time needed to reach flagrant insolvency is inversely proportional to the amount of bad mood spreading among investors. The effects of Markopolos are probably weak, pointing to the fact that even whistle-blowers do not accelerate the disclosure of the scam, unless they can trigger a cascade of redemptions (that is not modeled here).

We use a formal Pearson chi-square test to conclude that the Markopolos effect is statistically significant, even though its practical relevance may be small (in line with some exploratory and visual evidence obtained from simulations and non-parametric density estimation on the generated data).

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