Analysis of Banking Supervision via Inspection Game and Agent-Based Modeling

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Abstract. *Banks have exceedingly important role in economy and are therefore often meticulously regulated and supervised. This paper examines relationship between banks and banking supervisors and explores how supervisors can adapt their strategy and be more efficient in achieving supervisory goals. The relationship is evaluated from game theoretic perspective and an agent-based model of banks' and supervisors' behavior and interaction is created. Computer simulation of the model is constructed in NetLogo environment, results are presented and conclusions are drawn.*

Keywords. Banking supervision, inspection games, Agent-based Modeling, simulation, ABMS, NetLogo

1 Introduction

Note: The views expressed in this article are those of the author and do not necessarily reflect the views of the Croatian National Bank.

Banks are financial institutions that act as intermediaries between entities that have excess funds and entities that are in need of additional funding. They also have a vital role as enablers of payment transactions between various entities. All in all, in market economy banks have a key role and their smooth functioning is essential for the financial sector and economy as a whole. 1930s' Great Depression and the global financial crisis which started in 2007, as well as many other banking crises, clearly show that failure of systematically important banks can have devastating and long lasting effects on economy and society in general. Significance of systematically important banks has long been recognized and today, vast majority of countries conduct more or less strict monitoring of their banks and banking activities [8].

This monitoring of banks and their business conduct and practices is known as banking supervision. Banking supervision has several goals most notable of which are depositors' protection and reduction of systemic risk (risk that failure of one key institution will significantly disrupt other important institutions).

Basel Committee on Banking Supervision is a forum for international cooperation in relation to banking supervision which, among its other tasks, publishes documents that are generally viewed as best practices in banking supervision. One of the most notable publications is "Core Principles for Effective Banking Supervision" [2]. The document contains 25 principles which should guide banking supervision so that it is effective and efficient. However, although the abovementioned principles are more or less generally accepted as best practices, the last global financial crisis showed that their implementation is not straightforward and that there are numerous differences in principles' implementation, not least of which is the level of supervisors' involvement in management of banks [1]. On the other hand, there is evidence that the authors who studied in detail banking supervision and banking systems from all around the world made conclusions, especially those in favor of deregulation, which were proven unreliable or false during the last global financial crisis [8].

Literature on banking supervision often focuses on capital adequacy, credit, market and operational risk and macroeconomic influences on banks' operations. However, one very important aspect of banking supervision is relationship between banks and supervisors. The paper focuses on this relationship and intricacies of the interaction. The aim of the article is to explore whether and how banking supervisory authority can adapt its strategy in performance of banking supervision so that it is more efficient in achieving supervisory goals.

For the sake of clarity of analysis, understanding and simplicity, several assumptions and simplifications are made. Banking supervision is viewed as a direct one-on-one interaction between a bank and a team of supervisors (on-site supervision or examination) that is very similar to inspection. Secondly, banking supervision is observed primarily as compliance check in which supervisor verifies whether banks comply with a certain set of predetermined rules (regulations). And thirdly, a set

of resources restrictions is presumed. Banking supervision requires resources (lasts for some time during which supervisor cannot supervise other institutions) and supervisors have to choose whom to supervise – they cannot perform examinations of all the banks all the time.

Taking into account abovementioned assumptions, this paper will show that supervisors' knowledge of banks' greater propensity to violate some rules than others can help supervisors in adapting their supervision strategy and lowering the total level of violations in the system. The assumption that such difference in propensity exists is based on the facts that some rules are more resource intensive to implement (for all banks) and that banks' perceived benefit of implementation of some rules is lower than for others. Furthermore, this assumption, if proven correct, should guide further research aimed at direct and/or indirect identification of these differences. It is important to note that, although the hypothesis seems obvious, it is not necessarily such. For example, it is easy to deduct that if there really was such difference and if supervisors, based on that knowledge, adapted their supervision strategy, banks would also be prone to change their strategy, having less incentive to violate rules that they think supervisors will supervise and more incentive to violate other rules. In that way, this knowledge might even increase the total number of rule violations in the system.

2 Inspection games

Game theory presents a good starting point for study of interactions and strategic decision making.

Inspection games present a special class of non-cooperative games (in game-theoretic sense) in which one side (inspector) verifies whether the other side (inspectee) abides by certain rules. The inspector primarily wishes to deter unwanted activities performed by the inspectee by stimulating "good" behavior, and/or, more often, by punishing "bad" behavior. Inspectee prefers "bad" behavior if he can stay undetected by the inspector. In case of detection, inspectee would have preferred that he complied with the rules. Importantly, inspector usually has limited resources, so the detection rate can never be 100%.

Inspection games are best recognized for their application in the arms control and disarmament and crime economics although other applications are also known [7]. Impact of fines on regulated entities was studied by Tsebelis [25] and inspection games were also applied to banking supervision [4], because relationship between banks and supervisors can, in some cases, closely fit the outline described in the previous chapter.

Basic structure of an inspection game applied to banking supervision is shown in Fig. 1. (arrows show preferences of the players), with the relationships between payoffs for the bank shown in (1) and for the supervisor in (2).

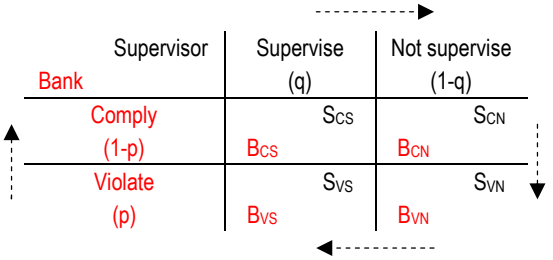

Figure 1. Payoff matrix

$$B_{CS} > B_{VS} \qquad B_{VN} > B_{CN} \qquad (1)$$

$$S_{CN} > S_{CS} \qquad S_{VS} > S_{VN} \qquad (2)$$

In line with the described payoffs, it is clear that both the bank and the supervisor will always have a reason to change their strategies; hence, the only equilibrium strategies are mixed strategies. The probability of bank violating the rules is marked with p, while the probability of supervisor performing supervision is denoted with q. Tsebelis has shown [24] that the optimal mix of pure strategies played by the players is given by (3) for the bank and by (4) for the supervisor.

$$p^* = \frac{S_{VN} - S_{VS}}{S_{CS} - S_{CN} + S_{VN} - S_{VS}} \qquad (3)$$

$$q^* = \frac{B_{CN} - B_{VN}}{B_{CN} - B_{VN} + B_{VS} - B_{CS}} \qquad (4)$$

It is important to note that these equations lead to some surprising conclusions, the most important of which is that penalty has no effect on crime. In other words, increasing or reducing penalty for observed violation of rules (B_{VS}) will not influence the frequency of violations in equilibrium (p*). This is important because it is usually intuitively assumed that higher punishment will act as a deterrent and reduce total level of violations. In a sense, equilibrium level of compliance vs. violation of a bank depends only on the payoffs to the supervisor and not on the payoffs to the bank. Tsebelis also concluded that increasing penalty leads to lowering of probability of supervision. In line with these conclusions, stimulations have equal but opposite effect on both parties.

This unexpected result provoked further research and motivated some critics to question the validity of Tsebelis' model, taking into account its narrowness (only two-person game) and lack of iterations [9]. On the other hand, based on Tsebelis' theorems, authors came to conclusions that "harsher anticorruption measures can increase crime incentives" [13] and that "increasing inspector's incentives to enforce law increases the frequency of law infractions" [6].

Franckx [12] concludes that small changes in the structure of penalties do not influence equilibrium state, but that larger changes influence inspectors' behavior, which is in line with Tsebelis' propositions.

Conversely, Pradiptyo in his work [18] concludes that harshness of punishment can deter non-compliance, but that impact of the punishment on inspectee's behavior is less certain than impact of crime prevention programs. However, these results apply only if the inspection levels stay the same.

Further developing the basic Tsebelis' model, Andreozzi [6] concluded that inspectors who conduct inspections for a long time (numerous iterations) might be more tolerant to non-compliance.

Experimental evidence with humans as inspectors and inspectees has shown that higher penalties do deter non-compliance, but also that humans slowly adapt to inspection [19]. Furthermore, Rauhaut and Junker [20] have experimentally shown that both players are affected by the level of punishment (fines) and that reason for punishment's effectiveness lies in human's bounded rationality. Other experimental evidence shows that penalties are more effective than stimulations in deterring unwanted behavior [17].

Different and sometimes contrary conclusions that are described above clearly show that there is no full agreement on how to explain some elementary relationships in the inspection game. Furthermore, it is clear that there is no universal model and changes to the basic model which aim to imitate more realistically real-world conditions significantly change expected outcomes and resulting conclusions. Also, devising mathematical solutions for models that are little more than elementary (and, hence, better describe real world conditions) proves to be challenging [11] or even impossible. On the other hand, experimental evidence is sometimes at odds with theory, especially taking into account conditions under which a theory holds and their real-world applicability.

Additionally, a model should realistically consider that both inspector and the inspected do not have perfect information on each other's payoffs and that they have constrained capacity. It was shown that these considerations present significant challenge for analytical methods [22].

All this leads to the conclusion that purely (game) theoretical approach to practical banking supervision problems might not be optimal.

3 Agent-based modeling

Agent-based modeling (ABM) enables construction of models in which numerous entities (agents) make autonomous decisions and interact with each other. Agents' (often simple) micro-level behavior cannot be directly used for prediction of large-scale outcomes, and produces sometimes unexpected macro-level results [23].

ABM has been noted for its use in modeling of economic markets, social psychology and other complex systems that are often inadequately described by more traditional modeling techniques because of simplifications and assumptions in traditional models that make them solvable, but also distance them from real world applications [14][23].

Agents, in general, have the following characteristics [14][15]:

1. Agent is an individual entity that is identifiable from other agents.
2. Each agent exists in an environment that is shared with other agents. Agent can interact with environment and with other agents.
3. Agents have goals and their actions are aimed at achieving these goals.
4. Agents make their own (self-directed) decisions.
5. Agents can learn and adapt their behavior based on changes in the environment and in other agents' behavior.

Based on abovementioned characteristics it is intuitively understandable that banking supervision might be described through ABM with banks and supervisors as agents that interact with each other. However, to formalize this applicability, if characteristics of banking supervision are compared with Macal and North's guideline on when to use ABM, it is visible that they fit well most of the mentioned cases [15]. Also, there is evidence on applicability of ABM on modeling of interactions that can be viewed as inspection games [19].

In the following chapter, a simple model of banking supervision is presented.

4 Banking supervision model

Nucleus of the model is relationship between two groups of agents - banks and supervisors. Agents' basic motivations are in line with inspector/inspected relationship described at the beginning of chapter 2. The diagram of the model is displayed in Fig. 2.

Agents make decisions autonomously, based on their payoffs. Banks can violate or comply with each of 2 rules (a bank can comply with one rule but violate the other), and supervisors can perform inspections (supervisions) in which they check compliance with only one rule. Banks have greater propensity to violate one rule (rule A) than the other (rule B), and supervisors are aware of this tendency.

Banks make autonomous decisions on whether to violate or comply with each rule. Since banks are heterogeneous entities, each bank has different (randomly created) payoff matrix. This randomness of total utility accommodates for banks' differences in size, complexity of processes and risk appetite. However, relationship between payoffs is in line with equations (1) and (2). Furthermore, payoff for violation of rule A is greater than payoff for violation of rule B, proportionally to the propensity factor. The

punishment for geting caught in violation is the same for each bank and acts as an "anchor" during creation of payoffs for each bank.

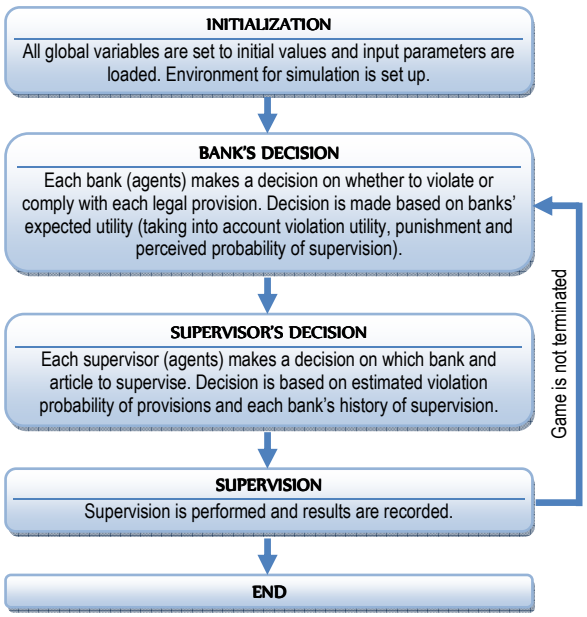

Figure 2. Diagram of banking supervision model

Supervisors are agents of an institution - banking supervisory authority and hence all have the same utilities, and all share the same knowledge on results of performed supervisions. Supervisors have limited resources and cannot supervise all the banks and all the rules. But, if they do perform supervision, they can determine violation with complete certainty. Supervisors do not know exact payoffs for each bank and make decisions based on the following knowledge:

1. Banks have greater propensity to violate rule A than rule B;
2. Supervisors know that a bank violated one of the rules only if some supervisor performed supervision of that bank and of that rule;
3. If supervisors know that a certain bank violated some rules, they assume that there is higher probability that it will violate it in the future (assumption of different risk appetites). This influence is stronger if violation occurred in recent past;
4. Supervisors assume that banks which were not caught in violation were compliant.

Based on that knowledge, supervisors calculate risk factor for each bank-rule combination and randomly select (with uniform distribution) banks and rules to inspect. In that way, probability for selecting high-propensity bank-rule combination is proportionally higher than selecting low-propensity bank-rule combination. Banks are aware how supervisors make their decision (points 1-4 above) and of the fact that supervisors cannot supervise all banks and rules in one "turn". Furthermore, banks can include information on number of supervisors and banks into their assessment of probability of supervision. However, because of randomness of supervisors' selection, banks cannot calculate rank-order of supervisors' selection and predict which banks and rules supervisors will inspect (if they could, they would know which rules they can violate without danger of getting caught and could adapt their strategy accordingly).

Both banks and supervisors are considered to be risk neutral in their decision making.

The presented model tries to mimic reality so that it can be used for test and verification of the hypothesis laid out in chapter 1. Of course, this model, in many ways, simplifies reality. However, the model still contains more complexity than inspection games elaborated in chapter 2 and is much more oriented towards a specific real-world problem. It is important to note that the model is characterized by a significant amount of randomness (e.g. different payoffs for each bank created with some randomness, each bank estimates with some imprecision and incomplete information probability of supervision, supervisors try to estimate probability of violation, etc.). The randomness has two goals. First, it helps to more realistically include the concept of bounded rationality into the model (incomplete information on one hand, but local "myopic" optimization on the other) and secondly, it enables construction of agents that are different among themselves, especially with respect to their risk appetite.

5 Simulation and results

Computer simulation of the model described in chapter 4 was developed and performed in NetLogo environment. NetLogo was chosen because of its simplicity, ease of use, high level of abstraction and resulting possibility for rapid development. Screenshot of simulation environment is shown is Fig. 3.

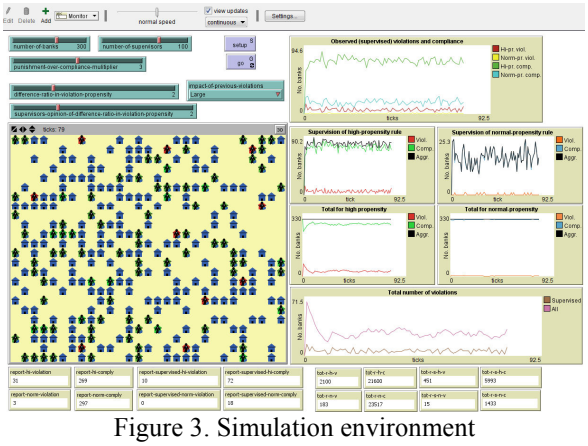
Figure 3. Simulation environment

Two simulation groups were run that differed only in supervisors' awareness of the difference in

propensity to violate rule A and B. Other parameters are shown in table 1.

Table 1. Simulation parameters

Parameter	Value
Nr. of banks	300
Nr. of supervisors	100
How much more "expensive" for the bank is to comply with rule A than rule B?	Twice
Nr. of turns per simulation	100
Nr. of simulations run	1,000

It is important to note that in one turn supervisor can supervise only one rule per bank (that is, in line with data in Table 1, in each turn there are 600 potential supervisions, and only 100 of them will materialize).

The results of simulations and basic statistical analysis are displayed in Table 2. It is visible that by changing assumption that supervisors are unaware of the difference between rules A and B with respect to the tendency for noncompliance, there was, on average and all other parameters being equal, over 18% decrease in total number of violations (for rules A and B). T-test clearly shows statistical significance of the result.

Table 2. Statistical alalysis

	Difference in propensity to violate	
	Unknown	Known
Nr. elements	1,000	1,000
Mean	2,735	2,242
Std. Dev.	397.4417	345.1481
Std. Error	16.646	
t-test	29.632, p << 0.001	

It is visible from the data that, if there really is a difference in propensity to violate, supervisors can change their supervision strategy and be more efficient without investing additional resources. Frequency-density histogram is shown in Figure 4.

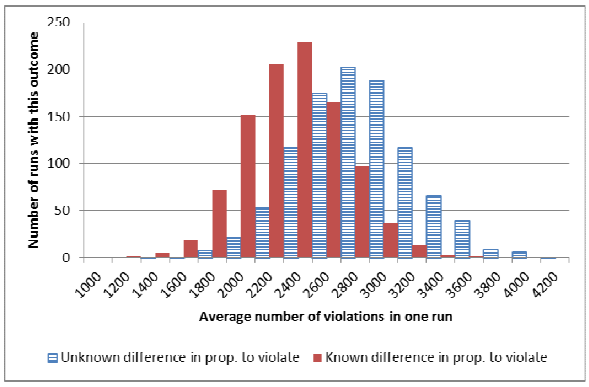

Figure 4. Frequency-density histogram

The model cannot, at this time, be sufficiently empirically validated primarily because of lack of high-quality empirical data. Some assumptions and parameters mentioned in chapter 4 are based on experience and were added to the model in line with steps 1-3 of the Werker-Brenner calibration [16][26]. However, as it was noted in chapter 1, the results of the simulation should guide further research and gathering of data. Part of the collection process should be aimed at collection of data that will be used for model validation. Sensitivity analysis of the model, as a part of model validation, was performed partly in line with recommendations of Richiardi et al. [21] by running simulations of all combinations of input parameters, by varying sample sizes and by varying seed for creation of random numbers. It was observed that the model is particularly sensitive to changes in ratio between the number of banks and supervisors. That is expected because smaller number of supervisors has a two-fold influence on the model:

- banks can (gu)estimate lower probability of supervision and because of that be more prone to violations,
- supervisors will perform less supervisions and hence the "risk-adjusting" influence of previous violations will include less banks.

6 Conclusion

This paper presented a model of interaction between banks and bank supervisors and showed that knowledge of the fact that banks are more prone to violation of some rules as opposed to other rules can help supervisors adapt their supervision strategy and be more effective in reaching their final goal (decreasing the total number of violations of rules). As it was already mentioned, this conclusion will lead further research which will try to verify that such differences in violation tendency truly exist. Furthermore, the research should enable supervisors to make distinction between regulatory rules based on the difference in violation propensity and to adapt their strategy accordingly. It would also be beneficial if quantification of this difference could be performed, because it would enable even better selection of optimal supervision strategy.

However, it is important to note that there are limitations related to the line of thought presented in this article and the laid out conditions. First of all, prevailing approach to banking regulation and supervision today is risk-based approach in which sometimes there are not many clear and fixed rules, but banks are required to follow some principles and fulfill some objectives. In that way, supervision becomes more of a dialog between banks and supervisors and determining compliance or non-compliance with regulations becomes increasingly difficult. On the other hand, the regulations themselves can sometimes be voluminous and very complex to understand, implement or check for compliance [3]. Of course, it is also questionable whether such regulations present a good framework for prudent bank management.

Furthermore, as it was stipulated in chapter 5, the presented model was not adequately empirically validated, taking into account lack of related empirical data. Planned further research should take that into account. Also, values of few parameters that were set based on experience should be additionally verified by submitting them to scrupulous analysis of domain experts (i.e. performing step 4 of Werker-Brenner calibration [16][26]).

The presented model might in the future also include some other real-world considerations that were omitted in this iteration because of clarity of analysis, simplicity and assumed lesser importance of these considerations. For example, if a bank was not supervised for some time, the probability for performing supervision should increase because of related uncertainty. Also, impact of historic violations on future supervisions could be better quantified.

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