Game theory

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Abstract

Game theory analyzes strategic decision making of multiple interdependent actors and has become influential in economics, political science and sociology. It provides novel insights in criminology, because it is a universal language for the unification of the social and behavioral sciences and allows deriving new hypotheses from fundamental assumptions about decision making. The first part of the chapter reviews foundations and assumptions of game theory, basic concepts and definitions. This includes applications of game theory to offender decision making in different strategic interaction settings: simultaneous and sequential games and signaling games. The second part illustrates the benefits (and problems) of game theoretical models for the analysis of crime and punishment by going in-depth through the "inspection game". The formal analytics are described, point predictions are derived and hypotheses are tested by laboratory experiments. The article concludes with a discussion of theoretical and practical implications of results from the inspection game.

1 Foundations of game theory

Most research on crime acknowledges that offender decision making does not take place in a vacuum. Nevertheless, most analytically oriented research applies decision theory to understand offenders. Tsebelis (1989) illustrates why this is a problem by using two examples: the decision to stay at home when rain is probable and the decision to speed when you are in a hurry. The first seems an appropriate problem for decision theory. An actor evaluates the probability of rain and the missed utility when staying at home and selects the alternative with the highest expected utility. The point here is that the probability of rain is independent of the strategy of the actor.

In contrast, the decision to speed is not such a game against "nature". Speeding can result in two different outcomes: getting faster to work or getting caught, fined and delayed. The probability of getting caught is not a "random", independent event; it depends on the activities of policemen, in particular on their resources and their strategy when and where to control speeding. For example, policemen will try to anticipate when and where speeders are frequent and may control more at traficked streets during rush hours than at remote places early in the morning. This may be anticipated by speeders, however, who may rather take side streets and drive faster at less obvious times. This, in turn, may also be anticipated by speed controllers and so on. In addition, there may even be further actors involved, such as victims, bystanders, judges, politicians and even journalists, whose actions may influence the actions of lawbreakers and guardians likewise.

Speeding, as many other offenses, should therefore be analyzed by a theory of interdependent decision making. Game theory provides a useful methodology for analyzing the interactional dynamics of interdependent decision makers. It enables deriving predictions of the decisions of offenders and law enforcers and fosters the understanding of the emerging macro-structural patterns of crime and control. Game theory has become influential in economics, political science and sociology. It is valuable for criminology because it forces theorists to make explicit assumptions about preferences and constraints of offenders, co-offenders, victims, guardians and law enforcement agents. This allows to model explicitly the strategic interaction structure between the involved players. This provides novel, interesting and testable hypotheses, which are derived from deep assumptions about interdependent decision making.

Game theory provides tools for analyzing how actors decide as if they tried to realize their preferences as good as possible under given restrictions. In particular, actors are assumed to take the preferences and restrictions of all other involved players into account. Hence it is assumed that everybody forms beliefs about the others' preferences and payoffs and maximizes own payoffs under these restrictions.

Game theory can be described as a universal language for the unification of the social and behavioral sciences (Gintis 2000, 2007). It may be described as a branch of rational choice theory—although the term "rational" is not necessary and may be confusing. It is also possible to describe game theory as a branch of "analytical sociology" (Hedström and Bearman 2009) or as a branch of law and economics (Baird et al. 1994). In general, it is a rigorous, mathematical approach for analyzing social interactions.

Game theory can be described by five elements (see also Diekmann and Voss 2004; Voss 2006; Raub and Buskens 2004). The most basic prerequisite of game theory is that actors hold resources which they can use for their goals. This requires at least two choice alternatives, from which actors can select. Resources can refer to opportunities and restrictions, such as time, money, market prices, institutions, social norms, legal rules, general policies, contracts, social control and also to probabilities of certain events such as detection of norm violations and expected severity of punishments.

Goals are typically referred to as "preferences". The most basic ones may be physical well-being and social approval. But also other-regarding preferences can be included such as inequity aversion (Fehr and Schmidt 1999), altruism (Andreoni 1989) or social value orientation (Van Lange 1999; Murphy and Ackermann 2013). Risk-preferences can be specified in terms of risk-neutrality, risk-aversion and risk-seekingness.

An important scope condition of game theory is its focus on situations of strategic interdependence. The probability that actor A reaches a certain goal depends on the strategies of all other involved actors $B, C, \ldots, Z$. Different to the case of of assessing the probability of rain, the probability of reaching a goal in interdependent social situations depends on the behavior and beliefs of other actors. A has to anticipate the decisions of $B, C, \ldots, Z$ and they have to anticipate the decision of A, given their own beliefs about the beliefs of A (and so on).

The theory also specifies a decision rule. In general, actors are assumed to use their resources such that they reach their goals "as good as possible". As good as possible could mean to maximize own utility, to maximize subjective expected utility or to merely satisfice a certain threshold under "bounded rationality". The most well-known decision rule is the "Nash equilibrium" (Nash

1951). The Nash equilibrium is a combination of strategies where all players maximize their expected utility, given all others' strategies. In equilibrium, no player has an incentive to unilaterally change her strategy. In other words, the combination of all strategies in equilibrium are best replies to each other. Note that the equilibrium is simultaneously a decision rule for individual actors and an aggregation rule, specifying how all decisions interact and generate a social structure.

In summary, game theory can be described by the following five elements:

1. The basic units of investigation are actors.
2. Actors hold resources, have preferences and can select among at least two alternatives.
3. The scope refers to situations of strategic interdependence, where the probability of reaching a goal depends on the decisions of all other involved actors.
4. Actors hold beliefs about the preferences, resources, choice alternatives and beliefs about the others actors.
5. The theory specifies a decision rule, how all actors decide. The decision rule is simultaneously the aggregation rule, specifying how all decisions aggregate to emergent social structures.

It cannot be repeated too often that these prerequisites do not imply specific assumptions about selfishness, farsightedness or rationality. Game theory is quite flexible and offers a general framework for analyzing social interactions. There is a whole branch of game theory analyzing how altruistic or prosocial actors decide in interdependent social situations (Camerer 2003). It is also not required that actors are assumed to be rational. Actors can be myopic (Jackson and Wolinsky 1996; Eaton and Wen 2008), bounded rational (Simon 1955) or even backward-looking learners (Macy and Flache 2002).

The specification of strategic interaction situations requires a minimal set of definitions (see also Braun and Gautschi 2011:147 f.):

Players refer to actors who engage in the same interaction situation. They can represent individuals, but also corporate actors such as organizations like the mafia, the police or political parties. Sometimes, “nature” is a fictitious additional player, referring to a random event.

Choice alternatives refer to the moves each player can make at a certain stage of the game. There are games in which players move simultaneously and others, where they move sequentially one after each other.

Information refers to the knowledge of each player at a certain stage of the game. “Common knowledge” refers to situations, when decision rules of all players, the structure of the game and the moves by nature are all known by all players and all players know that everybody knows (and so on). *Incomplete information* refers to the case that at least some parts of the structure of the game or the types of players are unknown to at least some players.

Strategies are complete rules which specify for each stage of the game which action is to be taken by the players. A *pure* strategy is a deterministic rule of action. A *mixed strategy* is a random distribution over pure strategies.

Payoffs refer to the utility players receive after everybody has decided about all alternatives at each stage of the game.

In what follows, I give intuitive applications of game theory in the fields of offender decision making, criminology and sociology of social norms, deviance and crime. For in-depth introductions to game theory see Dixit and Skeath (2004) and Gintis (2000), for game theory textbooks with a special focus on law and crime see Baird et al. (1994) and for a textbook about its empirical validity and development towards “behavioral game theory” see Camerer (2003).

2 Applications of game theory to offender decision making

The following examples illustrate how game theory can be used for analyzing offender decision making. The examples are structured by three fundamental categories of games. The first category refers to *simultaneous games*. Here each actor chooses her alternative without knowledge of the actions of all other players. The problem here is to build the best possible expectations about the others’ behaviors to get the best out of the situation.

Simultaneous strategic interaction situations are fundamentally different to *sequential games*. If games are sequential, at least one player has multiple moves, whose sequence is determined by at least one move of the opponent. The later players have at least some information of the moves of the earlier players so that they can make their strategy contingent on what the others have done.

The third class of examples refers to games with *incomplete information*. Here, at least some parts of the structure of the game are unknown to at least some players. I discuss cases where *alter* can have different types and this is only known to alter and not to *ego*. Ego has to move first, but can observe either a credible or an unreliable signal of alter.

Simultaneous games

Security Games are an important application of simultaneous games to offender decision making. A key characteristic of crime is that it cannot be controlled omnipotently. There are not enough resources to protect ports, airports, buses, trains, warehouses, schools and other infrastructure facilities around the clock. This means that security resources have to be deployed selectively. Speed controls at streets, drug control in trains or targeted weapon controls at airport operate at specific times and locations. However, any systematic pattern is likely to be exploited by adversaries. If speed patrols are always at the same street at Wednesdays 5 p.m., rushed commuters will soon realize it, drive only slowly at Wednesdays at the exact control spot and speed home at all other times and streets. Similarly, terrorist attackers will observe control patterns at airports and try to exploit systematic patterns.

Security games can be defined by two players, the defendant and the attacker, who have reversed payoffs. If the attacker attacks a target, while the defendant protects it, the attacker has worse payoffs than when it was not covered. The defender has the opposite payoff structure and is better off if she protects the target during an attempted attack. The defender's best strategy is to randomize such that control cannot be anticipated by the attacker. Randomization is, however, hard to do for humans and may require computational support in complex situations. Security games are extensively studied by Tambe (2011), whose research group has also developed a number of computational programs to assist airports, ports and other infrastructures to randomize their control and optimize their fielding of resources. Note that security game are also quite similar to inspection games (Tsebelis 1989; Rauhut 2009), which are extensively discussed in later sections. It is obvious from the description of security games that the players do not know the choices of their opponents when they have to select their own choices. Hence, the strategic interaction situation can be described by a simultaneous game.

Sequential games

In contrast to simultaneous games, sequential games refer to situations where actors decide one after each other and have at least some information about the previous moves of their opponents. A widespread application of a sequential game is the problem to place and honor trust.

Trust can be modeled by the so-called trust game (Dasgupta 1988; Camerer and Weigelt 1988; Coleman 1990; Buskens and Raub 2002). There are two players. The *trustor* moves first and has to decide whether to place trust in the *trustee* or not. If trust is denied the interaction terminates and the status quo remains. If trust is placed, the trustee can decide whether to honor or abuse trust. If trust is placed and honored, both players earn a higher payoff than the status quo. However, the trustee has a temptation to abuse trust, since she receives an even higher payoff than when honoring trust. In this case, the trustor receives the worst payoff. If this is anticipated by the trustor, trust is not placed and both cannot enjoy welfare gains. This payoff structure defines the trust problem and reveals two problems (Raub 2009): By placing trust, the trustor risks to be abused. If trust is not placed, however, both could have been better off than when trust had been placed and honored.

Examples of trust games are sending deficient products or delaying payments at Ebay (Diekmann et al. 2014), economic fraud at second-hand markets for used cars (Buskens and Weesie 2000) and taxi drivers who risk to be deceived or assaulted by bad custmoners (Gambetta and Hamill 2005). An interesting and classical instructive example of a serious offense is the strategic interaction between kidnapper and victim. Schelling (1960) depicts a kidnapper who has to decide to kill or return her hostage after having received the ransom money. The kidnapper prefers not to kill her hostage due to empathy and lower punishment in case of conviction. However, the hostage has seen the kidnapper's face and could reveal distinguishing marks to the police. The hostage promises to keep silent; however, once she has been released, her promise is not credible anymore. A solution to this problem is that the victim posts a remarkable hostage, such as committing a crime with the kidnapper as the only witness: "If the victim has committed an act whose disclosure could lead to blackmail, he may confess it; if not, he might commit one in the presence of his captor, to create the bond that will ensure his silence." (Schelling 1960:42-43)

Another important application of sequential games to offender decision making are "norm games" (Heckathorn 1989; Coleman 1990; Voss 2001; Fehr and Gächter 2002). In situations, where non–cooperative behavior and norm violations are observable by bystanders, but social control and punishment has to be enforced by informal observers, enforcement is often costly. The decision to admonish a polluter, to report a cheating student to the professor, to report a shoplifter to the store or to stop an aggressor harming his victim in a public street—all these examples entail costs to the informal enforcer. Third party enforcers may prefer that offenders are stopped and sanctioned. However, enforcement is often costly or risky. It often does not pay off to enforce a norm, especially if strangers interact who will never see each other again, so that future cooperative behavior of the norm violator cannot be enjoyed by the enforcer. This makes enforcement not credible, which is anticipated by offenders, making norm violations more likely. Game theory can help making predictions, under which conditions control and punishment is more likely to be performed and more likely to induce cooperative behavior (see e.g. Camerer 2003; Fehr and Gintis 2007; Diekmann et al. 2015)

Games with incomplete information

In games with complete information, all players know all choice alternatives, payoffs and other characteristics of the game of all players at any point in time. Games with *incomplete information* can be characterized by a preceding move by *nature*, which is unobserved by at least one player. A move by nature means that there is a random event, by which the game structure or by which the *types* of players are determined.

An important class of games with incomplete information are *signaling games*. Signaling theory analyzes an elementary problem of communication:

"How can an agent, the receiver, establish whether another agent, the signaler, is telling or otherwise conveying the truth about a state of affairs or event which the signaler might have an interest to misrepresent?" (Gambetta 2009b:168). A typical problem is to find out the type of the opponent: is she trustworthy or undeserving, cooperative or selfish, honest or dishonest, strong or weak, risk-seeking or risk-averse, hardworking or lazy, well connected or solitary, patient or impulsive, smart or naive? This class of games are particularly important for the analysis of offender decision making, because there are many traits and actions criminals, victims and police agents have an interest to hide.

Applications of signaling theory have to satisfy four conditions (Gambetta 2009b:172, 175):

1. There is some action, the receiver can do which benefits the signaler, whether or not she has a certain quality or type.
2. This action benefits the receiver if and only if the signaler truly has the property and otherwise hurts her.
3. There is information asymmetry between the signaler, who knows her type, and the receiver, who does not.
4. The signaler can commit an action with a cost which is sufficiently high so that it discriminates between truthful signalers and pretending mimicries. The action must have a sufficient cost differential between what a truthful signaler can and what a mimicry cannot afford to pay to receive the benefit of the receiver.

Instructive applications of signaling theory to offender decision making are given by Gambetta (2009a). Recommendable reviews and summaries of Gambetta's work are given by Przepiorka (2010) and Dixit (2011). An interesting example is the "job market" for criminals. It is risky to find trustworthy, serious co-offenders. Offenders want to avoid "wannabes" and undercover agents. An extreme, but in the mafia ubiquitous signal of seriousness is to commit a murder in the presence of others. While a serious offender aiming at a long-standing criminal career may afford such a signal, an undercover agent would never commit a murder just to establish trust.

This example fulfills all four conditions of signaling theory mentioned above. (1) The criminal employer (the receiver) can give a job in the criminal organization to the applicant (the sender), which benefits the applicant whether or not he is serious. (2) This action only benefits the employer if the applicant is a serious offender and hurts him if he is an undercover agent or a wannabe. (3) The applicant knows his type, but the employer does not. (4) The applicant can commit a murder to establish trust. The risk of conviction and the moral cost of committing a murder are outweighed by a long criminal career of a serious offender. An undercover agent cannot afford the risk and the costs of committing a murder, because this would not be covered by his agency. A wannabe cannot afford, because he is not serious and ruthless enough.

Another interesting example of Gambetta (2009a) is communication and fighting among prison inmates. One important goal of inmates is to establish a good standing in the prison hierarchy. One way of doing this is to engage in fights. However, fights are costly so that prison inmates do not want to waste energy with too weak opponents and do not want to risk loosing against too strong ones. Fighting ability can be communicated truthfully by scars from knife stabs or bullet wounds, indicating that the signaler has gone through and survived many fights. It is also possible to derive structural hypotheses from signaling theory about the level of aggression in different prison regimes. Interestingly, fights are more likely to occur in prisons with strict regimes, where encounters between prisoners are rare. Here, information about fighting ability is harder to communicate by signals so that it has to be experienced directly by going through many fights.

3 Crime and punishment from a game theoretical perspective

In what follows I give an in-depth example of a game theoretical model on crime and punishment, show results from several experiments of the model and discuss a number of theoretical and practical implications of the results. This shall illustrate the benefits (and problems) of game theoretical models in the area of offender decision making. I also go through the formal model and show how point predictions can be derived. By using monetary payoffs in experimental games, these predictions can be translated into real, detailed interaction situations, where behaviors of people can be compared with predictions. This allows empirical corroborations with high internal validity.

The impact of punishment severity on crime is a key topic for criminology and for understanding offender decision making. Game theory can offer novel insights on how punishment severity affects both the level of crime and the level of control. This yields a novel understanding of the strategic interaction structure between criminals and guardians.

The model is motivated by the fact that a certain proportion of offenses and crimes go undetected. Examples of which are tax evasion, doping in sports, fare dodging and many other forms of criminal behaviors. These socially undesirable behaviors are often monitored by inspectors such as policemen, conductors, guards, night watchmen, private detectives or doping testers. In these situations, offenders and inspectors typically have opposite incentive structures. While inspectors are rewarded for successful detections of crimes, offenders try to pass undetected.

A crucial problem is to find the right incentives to increase law-abidance. Standard approaches are to increase punishment severity (Becker 1968; Clarke 1995; Friedman 1995; Levitt 2002) or to increase rewards for successful inspectors (Allingham and Sandmo 1972; Andreoni et al. 1998). However, empirical deterrence research has shown that crime and control incentives do not affect respective behavior in such a simple and direct way (Cook 1980; Williams and Hawkins 1986; Nagin 1998; Doob and Webster 2003). It seems that punishment severity has relatively little impact on crime, while subjective beliefs about the detection likelihood are much more important (Kahan 1997; Lochner 2007). A game theoretical perspective can contribute a micro-mechanism showing how beliefs about detection probabilities of offenders and control agents interact dynamically so that they can explain some of the findings in empirical deterrence research.

Models without interdependent decision making

In classical rational choice theory, punishment severity and detection probability are the key variables for explaining crime. However, in the traditional approach, there is no interactive element—what matters is the utility maximization of offenders. The probability of punishment is typically fixed and not determined by beliefs and decisions of control agents.

The seminal article by Gary Becker (1968) builds the basis of such a “non-interdependent" decision making model on crime and punishment. Becker (1968) regards crime as rational behavior, accessible to standard market equilibrium analysis. Criminals are regarded as utility maximizers who optimize their payoffs under restrictions and risk. Criminals have clear incentives for criminal conduct; they gain material utility for theft or burglaries and also immaterial gains, such as for assaults.

The basic model of Becker (1968) can be specified as follows. Let offender i receive the combined monetary and psychic payoff y from a certain crime. Let her face conviction probability c to receive punishment p. Therefore, the expected utility π from crime for offender i is denoted by $\pi_i = c(y-p)+(1-c)(y)$ (see Becker 1968:177). This means with probability c crime is detected and punishment costs have to be paid, which is more loss than what is to be gained by crime. With the reversed probability $1-c$, payoffs from crime can be enjoyed without punishment costs.[1]

Now let s_i denote the likelihood that offender i commits the crime. Utility maximization of risk-neutral offenders implies that offenders commit crimes for sure (i.e. $s_i = 1$) when the expected utility from crime is positive (i.e. $y - cp > 0$). If expected payoffs from crime are negative (i.e. $y-cp < 0$), offenders refrain from crime (i.e. $s_i = 0$). By rearranging terms, the payoff of offender i can be written as

$$\pi_i(s_i) = s_i(y - cp). \tag{1}$$

From this perspective, higher punishment and higher conviction probabilities decrease crimes. Becker (1968) used this model to derive "optimal" levels of crime for a society for given punishment costs and harm done to victims.

While Becker's analysis focuses on offenders' decisions, it completely neglects decisions of control agents. Yet, the detection probability is largely driven by beliefs and decision making of control agents. This implies that crime is a strategic interaction problem between offenders and control agents. Crime cannot be analyzed by only focusing on offenders' decisions. More generally, if decision theoretical problems are confounded with problems of strategic inter-

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[1] Note that criminal gains are still received when punished. This is the case in the original model by Becker (1968) and is also kept in the later game theoretical model. This may reflect crimes, whose benefits remain to some extent, for example assaults or murder. It can also be argued that some benefit always remains, i.e. keeping a loot or gaining criminal experience. See also the original article by Becker for further arguments.

action, conclusions are often misguided. Tsebelis (1989) coined this confusion between decision and game theoretical reasoning the Robinson Crusoe fallacy. For the case of crime and punishment, there may be a lack of incentives for individual police officers to make large inspection efforts.

Game theoretical model of interdependent decision making

The model of Becker (1968) ignores interdependent decision making: the detection probability is modeled as an exogenous factor. This ignores that detection probability is generated by the beliefs and the decision making of inspectors.

A specific model of strategic interdependent decision making between offenders and control agents is the so-called "inspection game". The inspection game has been theoretically developed by Tsebelis (1989, 1990). Graetz et al. (1986) proposed even earlier a similar game with respect to tax compliance. Notable is also even earlier work by Wittman (1985), who exemplifies counterintuitive results in games with mixed strategies (although he does not explicitly apply these games to inspection situations). Holler (1993) discusses an inspection game structure with respect to pollution, where polluters play against enforcers. The first experimental test of inspection games has been contributed by Rauhut (2009). Agent-based simulations of learning models in inspection games and their experimental test is given by Rauhut and Junker (2009). A review of the mathematical properties of inspection games is given by Andreozzi (2010).

The inspection game is based on the assumption that the payoffs of offenders and control agents are in complete conflict, where success of one party implies failure for the other. Rational and selfish offenders will commit crimes when they believe not to be caught and rational and selfish control personnel will make inspection efforts when they believe offenders will commit crimes. The underlying payoff structure is formally called a "zero-sum game".

The inspection game can be formalized as follows. The offender part is similar to the rational choice model of Becker (1968). Offender i can decide to commit a crime with payoff y and punishment costs p if caught. If she does not commit a crime, her payoffs remain unchanged.

The novel part in the game theoretical model is the specification of the decision making structure of control agents. Inspectors can decide to inspect offenders. Inspector j has to invest inspection costs k to detect the action of offender i. If an inspector catches the offender for having committed a crime, the inspector receives the reward r. If not successful, inspection costs are lost. If she does not inspect, she remains at her payoff level. It is further assumed that undetected crime is attractive and punishment is a real threat, i.e. that $p > y > 0$.[2] Likewise, inspectors are assumed to gain from successful inspections, i.e. $r > k > 0$. The strategic interaction between offenders and control agents is illustrated by the 2×2 game matrix in the so-called “normal form” (Table 1).

Normal form means a matrix, where the choice alternatives of row and column players are written in respective rows and columns. The payoffs of the strategy combinations of row players are written at the left and payoffs of column players at the right side of the comma.

Table 1. The inspection game

		inspector j		
		inspect		not inspect
offender i	crime	$y-p$, $r-k$	$\Leftarrow$	y , 0
		$\Downarrow$		$\Uparrow$
	no crime	0 , $-k$	$\Rightarrow$	0 , 0

with $p > y > 0, \quad r > k > 0$

The payoff structure has the implication that rational, selfish and payoff maximizing offenders commit a crime if not inspected and abide the law if inspected. In contrast, rational, selfish and payoff-maximizing inspectors perform inspections if offenders commit a crime and do not inspect if offenders do not commit a crime. This has the consequence that there is no “dominant strategy”. This means that there is no best decision regardless of the decision of the opponent. The absence of a dominant strategy is illustrated by the circling arrows in Table 1. They mean that ego always has a reason to change her strategy, once the strategy of alter has changed. However, once ego updates her strategy and

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[2] If the cost of punishment p would be smaller than the payoff from crime, then a payoff-maximizing actor would always commit a crime, whatever the likelihood of punishment. For example, if the punishment of fare dodging would be smaller than the ticket price and no extra ticket price would be taken if fare dodgers were detected, then a payoff-maximizing passenger would never buy a ticket. If this situation would be modeled in a game with payoff-maximizing agents, the offender would always offend. This means that punishment severity (between nothing and the ticket price in this example) would not affect the rate of offending, which would always be 100%.

changes her behavior, alter becomes a reason to change her strategy as well, giving another reason for ego to change again and so on.

These circling, indefinite changes of best responses can be demonstrated as follows. Let us start in the upper left corner of Table 1. If the inspector inspects and the offender commits a crime, the offender receives a punishment which exceeds the reward from crime. This strategy combination is, therefore, not in equilibrium. Therefore, the offender decides to change her strategy and commits no crime. In this case, the inspector pays inspection costs k without receiving the reward r. Hence, the inspector changes to the better response not to inspect the offender. In this case, however, the offender receives an incentive to commit a crime, because she would receive payoffs from crime y without punishment p. This strategy combination, however, gives the inspector an incentive to change her strategy to inspection, yielding for her the better payoff $r - k$, which is more than nothing. Yet, this strategy combination has been the starting point of our analysis and is no equilibrium in pure strategies either, i.e. the offender changes to no crime and so on.[3]

This demonstrates that there is no combination of strategies, where both actors have no incentive to unilaterally change their strategy. In this case, actors can "mix" their strategies. This means that players choose a certain probability to perform one of their alternatives. The best way to do this is to respond with the best possible strategy mix given the mix of the opponent. If both parties optimize their respective probability to commit a crime and to perform inspections, the equilibrium in probabilities is such that offenders choose the probability for crime at the indifference point of inspectors and inspectors choose the probability of inspection at the indifference point of offenders.

The intuition for the equilibrium of optimal crime and inspection probabilities may be illustrated by the following consideration: An offender who commits crimes no matter what will sooner or later receive many punishments in a row. On the other hand, a "big-brother" control regime, where the inspector invests in omnipresent inspection will be highly inefficient because crimes will decrease up

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[3] Note that strategic settings without dominant strategies and ones without Nash equilibria in pure strategies are formally not the same. Dominance means that a strategy is better regardless of what the opponent chooses. Combinations of dominant strategies are always Nash equilibria. Nash equilibria in pure strategies are more general and can also specify strategy combinations, where mutual best replies are contingent on the other player's move. For example, driving on the right side if the other is also driving right, and driving left if the other is driving left.

to a minimum and control activities will no longer amortize. As a consequence, both parties will choose a mixed rather than a "pure" (fixed, deterministic) strategy.[4]

The equilibrium in mixed strategies has the interesting, counter-intuitive implication that more severe punishments do not decrease the crime rate. The point is that a mix of strategies is only in equilibrium if both actors make their opponent indifferent between their two alternatives. If one actor is not indifferent, she will take advantage and exploit the other which gives an incentives for the other to change her strategy and so on. The only stable probability combination is such that the opponent is indifferent between both alternatives. This is why the payoffs of alter determine the probability choice of ego.

The equilibria in mixed strategies can be formalized as follows. Let s_i denote the probability that offender i commits the crime and c_j the probability that inspector j inspects offender i. A value of zero means no action (no crime and no inspection), a value of one means a fixed action (crime or inspection) and values between zero and one mean that the actor chooses a probabilistic (mixed) strategy.

This allows to define the payoff functions for offenders and inspectors in the following way. The payoff function π for offender i who plays against inspector j is given by

$$\pi_i(s_i, c_j) = s_i(y - c_j p).$$

The payoff function ϕ for inspector j who plays against offender i is

$$\phi_j(s_i, c_j) = c_j(s_i r - k).$$

The payoff functions consist of the payoffs from Table 1 and the strategies specified above. For example, if offender i chooses to commit a crime ($s_i = 1$) and the inspector chooses to inspect offender i ($c_j = 1$), then the payoff for offender i is $y - p$ and the payoff for inspector j is $r - k$. Another example is that the offender chooses a probabilistic strategy of 50 % to commit a crime ($s_i = 0.5$) and the inspector does not inspect ($c_j = 0$). Then, the offender's

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[4] There is a discussion whether mixed strategies are a plausible prediction in zero-sum games. Holler (1990, 1993) argued that maximin strategies were more plausible. See the discussion therein and the summary by Andreozzi (2010).

payoff is $0.5 \times y$ and the inspector's payoff is 0.

The best response is the best strategy for a given choice of the opponent. Best responses of offenders are calculated by the first partial derivative of the payoff function, i.e. $\frac{\partial \pi_i}{\partial s_i}$:

$$s_i^*(c_j) = \begin{cases} 1 & \text{if } y - c_j p > 0 \\ [0,1] & \text{if } y - c_j p = 0 \\ 0 & \text{if } y - c_j p < 0. \end{cases} \tag{2}$$

Equation 2: offender's best crime responses for given inspection decisions

From the first line, it can be seen that the offender's best response is to commit a crime for sure if the expected payoff is positive, thus if the payoff from crime y is higher than the expected loss from punishment ($c_j \times p$). The expected loss from punishment is simply given by the probability that the inspector chooses to inspect (c_j), which is multiplied with the punishment cost p. From the third line, it can be seen that the offender's best response is to commit no crime for sure if the expected payoff is negative, thus if the payoff from crime y is lower than the expected loss from punishment ($c_j \times p$). The second line shows that the offender is indifferent for the case that the payoff from crime y is equal to the expected losses from punishment ($c_j \times p$). Indifference means that any probability to commit a crime yields the same payoffs for the offender. Thus, the offender's best response is anything between no crime ($s_i = 0$), crime with some probability ($0 < s_i < 1$) and crime for sure ($s_i = 1$).

Inspector's best responses j are calculated in a similar way, using the first partial derivate of the inspector's payoff function $\frac{\partial \pi_j}{\partial c_j}$. This yields

$$c_j^*(s_i) = \begin{cases} 1 & \text{if } s_i r - k > 0 \\ [0,1] & \text{if } s_i r - k = 0 \\ 0 & \text{if } s_i r - k < 0. \end{cases} \tag{3}$$

Equation 3: Inspector's best inspection responses for given crime decisions

From the first line, it can be seen that the inspector chooses to inspect for sure ($c_j = 1$) if the expected payoff from inspection ($s_i \times r$) is larger than the inspection costs k. The expected payoffs from inspection are simply given by the probability that the offender chooses to commit a crime (s_i), which is multiplied by the reward for successful inspection r. From the third line, it can be seen that the inspector's best response is not to inspect for sure if the expected payoffs from inspection ($s_i \times r$) are lower than the inspection costs k. The second line shows that the inspector is indifferent for the case that the payoff from inspection ($s_i \times r$) is equal to the inspection cost k. Thus, any probability to choose inspection yields the same payoffs for the inspector. Thus, the inspector's best response is anything between no inspection ($c_j = 0$), inspection with some probability ($0 < c_j < 1$) and inspection for sure ($c_j = 1$).

The best response analysis reveals that there are no pure strategies in equilibrium. If the offender chooses to commit a crime for sure ($s_i = 1$), the inspector's best response is to inspect for sure ($c_j = 1$), for which the best response for the offender is to commit no crime for sure ($s_i = 0$), for which the best response for the inspector is to perform no inspection for sure ($c_j = 0$). Therefore, both have to choose a probabilistic strategy. The only stable strategy combination is that both are indifferent between their choices. The second line of the best response functions in equations 2 and 3 indicate the indifference conditions. The combination of indifference points yield the equilibrium in mixed strategies. This equilibrium implies for offenders to choose a crime with probability

$$s_i^* = \frac{k}{r}. \tag{4}$$

Equation 4: Predicted probability of offenders to commit crimes

This shows that the crime rate only depends on the inspector's payoffs, thus on the inspection cost k and the inspection reward r.

This effect will also be called the "strategic incentive-effect". This term denotes the prediction that ego's incentives only affects alter's behavior and vice versa. The strategic incentive effect has the counter–intuitive implication for inspection games that punishment does not affect crime rates. Crime rates are only affected by inspection incentives and inspection costs.

Game theoretical prediction 1. *Punishment severity has no impact on crime.*

Game theoretical prediction 2. *The stronger the inspection incentives the lower the crime rate.*

The equilibrium in mixed strategies for inspection is calculated by the indifference condition of the offender. Thus, the inspector chooses to perform an inspection with probability

$$c_j^* = \frac{y}{p}. \tag{5}$$

Equation 5: Predicted probability of enforcers to perform inspections

Therefore, the rate of controls only depends on offenders' payoffs, thus on gains from crime y and punishment costs p. Hence, the "strategic incentive-effect" also holds for inspections.

Game theoretical prediction 3. *The level of inspection incentives has no effect on inspection behavior.*

Game theoretical prediction 4. *More severe punishments cause less inspections.*

The counter–intuitive implication is that inspection incentives do not affect inspection rates. Inspection rates are only affected by criminal gains and punishments.

Backward-looking rationality

The strategic incentive-effect that more severe punishment reduces control and stronger inspection incentives reduce crime occurs for perfectly farsighted actors right from the start. Farsighted means that actors form a belief about the future behavior of their opponent and perform a payoff-maximizing strategy throughout all future interactions given their current belief. This actor type is also called "forward-looking" (Macy and Flache 2009).[5]

The strategic incentive-effect also occurs for actors who are not farsighted but who learn the behavior of their opponent step by step by experience. These

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[5] Note that the inspection game has also been extended to a sequential version, in which the inspector can commit himself to a probability of inspection. This is beyond the scope of this introduction; see Andreozzi (2004) for details.

"rational learners" form a belief based on their previous experience and perform a payoff-maximizing choice given their experience. They also update their beliefs throughout the course of all upcoming interactions. This actor type is also called "backward-looking" (Macy and Flache 2009). This requires less assumptions. The forward-looking game theoretical reasoning assumes that (1) actors anticipate the behavior of their opponent correctly and (2) all actors know the payoffs of their opponents. In the learning model, actors are not perfectly farsighted but learn the detection probability by experience. Furthermore, learning actors do not have to know the payoffs of their opponent, but react on the previous choices of their opponent by a payoff-maximizing response.[6]

It can be shown that forward-looking and backward-looking rationality predict equivalent dynamics.[7] (1) More severe punishment does not affect crime but reduces control and (2) stronger inspection incentives do not affect inspections but reduce crimes. The dynamics—in which individual offenders and enforcers make reasonable decisions given the information they have — leads to the "strategic incentive effect" for farsighted agents in the first time step and for rational learners after some time. Perfectly farsighted agents anticipate the complete course of the dynamics at once and rational learners go through some learning periods after which they show the same aggregate behaviors.

4 Empirical evidence on inspection games

The game theoretical model is difficult to test in the field. In field settings, it is easier for researchers to get information about policy than about actual enforcement efforts by control personnel. Relatedly, it is difficult to get data on offenders' reactions to actual enforcement levels. Further, it is difficult to observe the dynamic interplay of behaviors in the field. These likely data limitations in conjunction with other third factors that may covary means that it is difficult to track the feedback loops between criminal activity and control efforts. In addition, it is difficult to solve the endogeneity problem in the field:

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[6] The learning model can be described as backward-looking rationality since actors adapt their behavior with a best response to the past behavior of their opponent. This model is also known as fictitious play (Fudenberg and Levine 1998) or Bayesian updating. Note that there are also alternative backward-looking learning models, some of which are described in Macy (1991, 1993) and Macy and Flache (2002).

[7] For the precise learning dynamics see Rauhut (2015); Rauhut and Jud (2014) and Rauhut and Junker (2009).

do high crime rates affect the level of punishment severity or does punishment severity drive the level of crime?

In the laboratory, these methodological concerns can be addressed.[8] Rauhut (2009) conducted experiments that manipulated the severity of punishment and another series which manipulated the incentives for law enforcement to pursue criminals (Rauhut 2015). Because the laboratory setting allows to manipulate punishment severity, the endogeneity problem that the crime rate may cause changes in punishment severity is eliminated. In addition, the experiments enabled measuring the decicions of both offenders and control agents—something that is often difficult to do in natural settings—so that feedback loops between crime and control could be tracked.

Both experimental series had a similar structure. There were two offenders and two law enforcers randomly matched in each period (so-called "stranger-matching"). Participants were randomly assigned to be in either the offender or the law enforcer position throughout the whole experiment. The participants interacted with each other for 30 rounds. On each round, offenders had the opportunity to steal money from each other. Also on each round, law enforcers were able to investigate crime—that is, to determine whether theft occurred. Law enforcers earned money by catching criminal offenders and criminal offenders were subject to monetary fines.

The experimental treatments varied the level of punishment severity and law enforcement incentives and their order. In the first series of experiments (Rauhut 2009), punishment severity was varied between mild and severe. In one condition, the first 15 periods were mild punishment and changed then to severe punishment. In the second condition, the order was reversed, starting with 15 periods severe punishment followed by 15 periods mild punishment. In the second series of experiments (Rauhut 2015), inspection incentives were varied with the same structure: in one condition 15 periods little inspection incentives followed by strong inspection incentives and in the other condition the reversed order.

What happened? In the first experiment, more severe punishment led to lower rates of enforcement. When collapsed over both orders of treatments, the average enforcement rate for mild punishment was 56%; when punishment was

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[8] For a more in-depth discussion of how laboratory experiments can be used for studying crime and law see Horne and Rauhut (2013) and for an extensive disucussion of their validity see Rauhut and Winter (2012).

severe, the average enforcement rate dropped to 42%. This 14 % decrease of inspections for more severe punishments was statistically significant at the 0.1 % level.[9]

Increasing the severity of punishment also discouraged theft, however. Taking the average over both orders of treatments, severe punishment yielded a theft rate of 43 % and mild punishment a theft rate of 65 %. This 22 % decrease of thefts for more severe punishments was also statistically significant at the 0.1 % level.[10] Note that the severity of punishment affected crime more than expected, suggesting that subjects were not good at anticipating that law enforcers were going to reduce their efforts.

Experiment 2 produced complementary results and provided additional support for the proposed mechanism (Rauhut 2015). It showed that as rewards for enforcement were increased, crime rates dropped from 52% to 40%. Enforcement efforts also increased from 38% to 66% in regimes with strong enforcement incentives. These percentages denote the averages over all periods and both orders of treatments. The decline of crimes by 12 % and the increase of inspections by 28 % for increased inspection incentives were statistically significant at the 0.1 % level, computed by logistic random intercepts models.

The different strategic interaction patterns between offenders and enforcers for control regimes with different levels of punishments and enforcement incentives can also be analyzed dynamically. Figures 1 and 2 show the dynamics of crime (panel A) and inspection decisions (panel B) over time. Figure 1 shows crime and inspection dynamics for the treatments with fifteen consecutive periods of mild (left) and severe punishment (right) from the data of Rauhut (2009). Figure 2 shows crime and inspection dynamics for little and strong inspection incentives from the data of Rauhut (2015). For both figures, the data is pooled with respect to treatment order. Gray lines in each subpanel show the predicted mixed Nash equilibria and error bars denote 95 % confidence intervals of each rate at each period.

The dynamics show that there is a sharp change in behaviors when punishment and inspection incentives are changed. After the strong behavioral change, however, crime and inspection rates do not converge towards predictions over time. Crime and inspection rates remain relatively stable over time.

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[9] Statistical significance here is estimated by a logistic random intercepts model.

[10] Statistical significance is again estimated by a logistic random intercepts model.

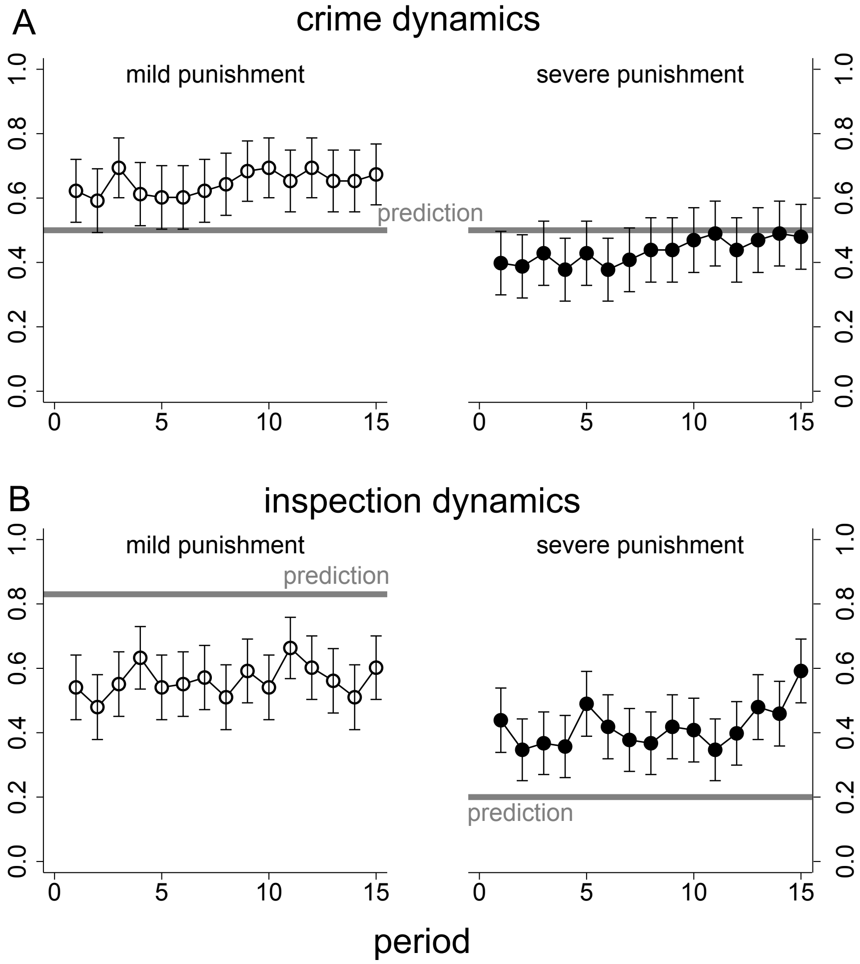

Figure 1. Crime and inspection rates over time for mild versus severe punishment conditions. Panel A shows theft rates over 15 periods with mild punishment (left) and 15 periods with severe punishment (right). Panel B shows respective inspection rates (left mild, right severe punishment). Rates are collapsed over the order of punishment severity treatments (experiment 1 with mild punishment as first condition and experiment 2 with severe punishment first). Gray lines in each subfigure show respective predictions from mixed Nash equilibria. Error bars denote 95% confidence intervals for each rate at each period (consisting of 98 observations each). Data source: Rauhut (2009).

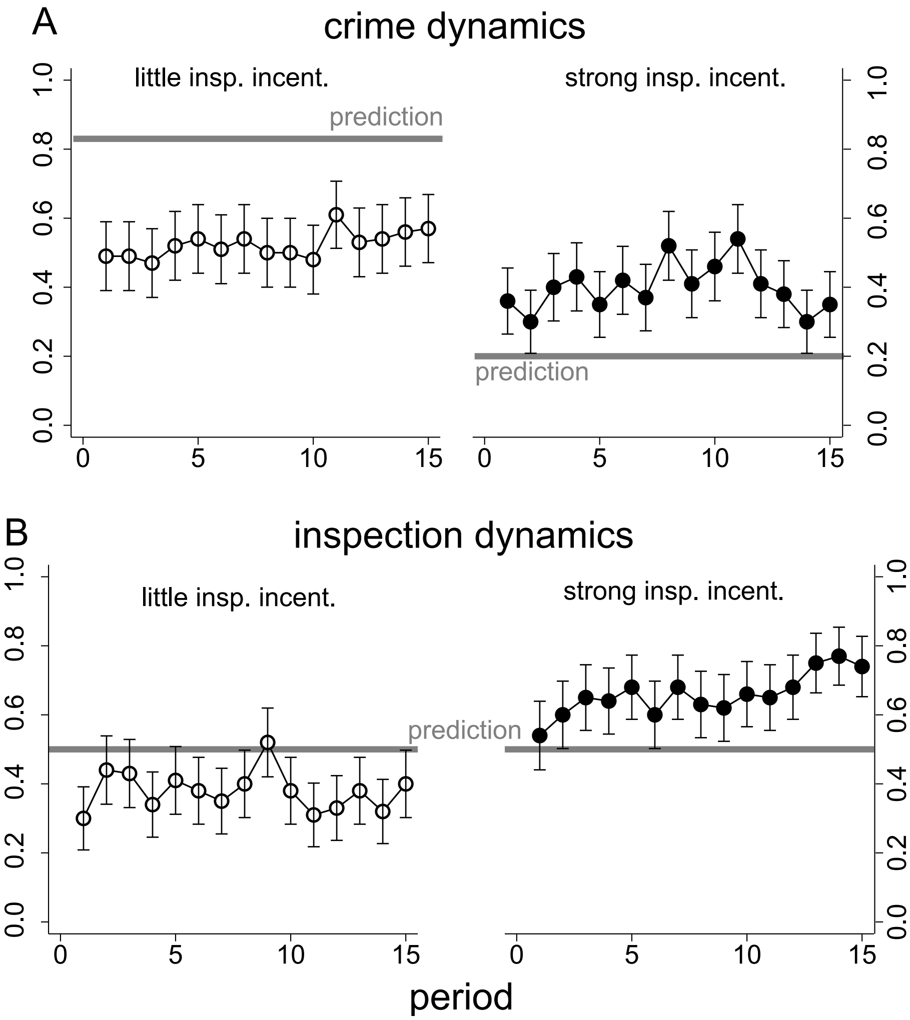

Figure 2. Crime and inspection rates over time for little versus strong inspection incentive conditions. Panel A shows theft rates over 15 periods with little inspection incentives (left) and 15 periods with strong inspection incentives (right). Panel B shows respective inspection rates (left little, right strong inspection incentives). Rates are collapsed over the order of inspection incentive treatments (experiment 1 with little inspection incentives as first condition and experiment 2 with strong inspection incentives first). Gray lines in each subfigure show respective predictions from mixed Nash equilibria. Error bars denote 95% confidence intervals for each rate at each period (consisting of 100 observations each). Figure from Rauhut (2015).

Taken together, these experiments provide evidence that incentives (punishments for criminals and rewards for enforcers) not only have direct effects on behavior; they also have indirect effects. Because offenders and control agents have opposing interests, each is sensitive to the incentives of the other. They change their behaviors in response to the behaviors of others. But the results also suggest that people are not as sensitive to the payoffs of their opponent as the theory would predict—people seem to be slow in updating their beliefs about the detection probability.

5 Discussion

Most rational choice theories on offender decision making imply that more severe punishments cause lower crime rates. However, many field studies could not confirm strong effects of punishment severity on crime. A game theoretical perspective offers an explanation by a mechanism linking offender decision making with decision making of control agents. The game theoretical argument focuses on the opposite incentive structure between criminals and control agents. Due to this "zero-sum" game between criminals and control agents, incentives of both parties have counter-intuitive effects. From a theoretical point of view, offenders' incentives only affect control agents' decisions and control agents' incentives only affect offenders' decisions. This reversed effect of ego's payoffs on alter's behavior is also called "strategic incentive effect". This has two major implications. More severe punishments reduce control behaviors and stronger control incentives reduce criminal behaviors.

The game theoretical mechanism is difficult to test in the field. Much crime is undetected and offenders do not freely report their decision making and beliefs in offender surveys. Relatedly, it is difficult to elicit precise information about enforcement efforts by control personnel and their beliefs about offender decision making. Field data also has an endogeneity problem in the sense that it is not known whether crime rates affect the level of punishment severity or whether punishment severity drives the level of crime. Furthermore, field data often cannot disentangle unrelated covariates from causal factors, leading to spurious correlations which may be falsely interpreted as confirming or disconfirming evidence for theories of offender decision making. However, much of the empirical research in criminology and law relies on official crime statistics, surveys and observational data, which is often limited to descriptive evidence of the correlates of crime (Sampson 2000). Laboratory experiments are able to test causal relations and mechanisms and help illuminating mechanisms at the micro-level and their aggregation to macro-level patterns of behavior.

The results from the laboratory experiments show that more severe punishment causes lower inspection rates, supporting the main game theoretical implication. However, not only inspection is affected by punishment, but crime as well. If punishment is more severe, there is less control *and* less crime. Hence, there is both, a strategic incentive effect (higher punishment causes less control) and an own incentive effect (higher punishment causes less crime). These findings are qualitatively supported in the second series of laboratory experiments. Here, stronger inspection incentives cause less crime. However, stronger inspection incentives also increased control. This series complements the findings from the punishment experiments, confirming strategic *and* own incentive effects.

The own incentive-effect could partly be explained by less sophisticated calculations and less anticipatory reasoning by offenders. Instead, offenders may primarily use rules of thumb and "heuristics" in decision making (Gigerenzer and Goldstein 1996; Todd and Gigerenzer 2000). Such offender heuristics specify easier decision rules. A simple example of an offender heuristic is a reversed tit-for-tat strategy: commit a crime if no inspection occurred previously and do not commit a crime if there has been an inspection recently. Respective follow-up experiments (Rauhut and Jud 2014) show that this can partly explain the findings. However, there are also offender types who care about payoffs of other offenders. This other-regarding type cares about becoming a victim of crime and retaliates by committing more crimes to any others than what would be individually payoff-maximizing.

Another approach to explain the own incentive-effect is to assume that people expect others to make errors and do not behave in a perfectly farsighted and calculating way. Therefore, they may form beliefs about the probability of each of their opponents' choice alternatives. This can be modeled by the so-called "quantal response equilibrium" (McKelvey and Palfrey 1995). The intuition behind this model is that errors of the opponent can become very costly if ego does not anticipate these errors and take them into account in calculating expected payoffs from choice alternatives. For example, if the punishment is very high, citizens may doubt that inspectors indeed perform only very few controls. If citizens err on this side, they face a very high punishment, which they may try to avoid. Reversely, if the control incentive is very low, inspectors may doubt that criminals perform many crimes. If inspectors err on this side, their control efforts may not amortize so that they may decide to control less if there are only little incentives for control. Nosenzo et al. (2012) support predictions from this so-called "quantal response equilibrium" with data from simpler versions of the inspection game than presented here.

In addition to contributing to actor models in the social sciences, the game theoretical framework has also implications for political decision makers. Deterrence policies are often based on too simple theoretical mechanisms. The rhetorics of politicians frequently focus on arguments based on the "own incentive-effect": punishment severity is only thought of as a crime deterrence and not as an inspection deterrence. Likewise, inspection rewards are typically created in order to motivate inspections, neglecting their effect on crime. Especially, if crime is on the rise or if single criminal events are widely discussed in the press, politicians come up with the narrow argument that more severe punishment would help to reduce crime.

Given the results of the human subject experiments, policy recommendations should take two considerations into account: (1) crime is an interdependent strategic interaction situation between offenders and enforcers and (2) both actors types should be assumed to behave according to behavioral rather than classical game theory. This means that the creation of incentives should always take all involved players into account. In addition, these players should be modeled to be less caluculating, less adaptive and less farsighted, but more prosocial, more other-regarding and more sensitive to others' mistakes than what is assumed by classical rational choice models.

The presented game theoretical framework may also have implications for a welfare analysis of optimal control. For example, it may be cheaper to increase rewards for police and other control agents with the main aim to deter crime. Utilizing the strategic incentive-effect for the design of crime deterrence policies could give rise to more effective and cheaper deterrence. Deterrence policies should carefully take these considerations into account to be efficient and successful.

References

Allingham, Michael G. and Agnar Sandmo. 1972. "Income tax evasion: a theoretical analysis." *Journal of Public Economics* 1:323–338.

Andreoni, James. 1989. "Giving with impure altruism: applications to charity and Ricardian equivalence." *The Journal of Political Economy* pp. 1447–1458.

Andreoni, James, Brian Erard, and Jonathan Feinstein. 1998. "Tax Compliance." *Journal of Economic Literature* 36:818–860.

Andreozzi, Luciano. 2004. "Rewarding policemen increases crime. Another surprising result from the inspection game." *Public Choice* 121:69–82.

Andreozzi, Luciano. 2010. "Inspection games with long-run inspectors." *European Journal of Applied Mathematics* 21:441–458.

Baird, Douglas G., Robert H. Gertner, and Randal C. Picker. 1994. *Game theory and the law*. Cambridge, Mass.: Harvard University Press. Douglas G. Baird, Robert H. Gertner, Randal C. Picker. 24 cm.

Becker, Gary S. 1968. "Crime and Punishment: An Economic Approach." *Journal of Political Economy* 76:169–217.

Braun, Norman and Thomas Gautschi. 2011. *Rational Choice Theorie*. Weinheim, M?nchen: Juventa.

Buskens, Vincent and Werner Raub. 2002. "Embedded trust: Control and learning." *Advances in Group Processes* 19:167–202.

Buskens, V. and J. Weesie. 2000. "An experiment on the effects of embeddedness in trust situations - Buying a used car." 12:227–253. Times Cited: 2.

Camerer, Colin. 2003. *Behavioral game theory: Experiments in strategic interaction*. Princeton University Press.

Camerer, Colin and Keith Weigelt. 1988. "Experimental tests of a sequential equilibrium reputation model." *Econometrica* 56:1–36.

Clarke, R.V. 1995. "Situational crime prevention." *Crime and justice* pp. 91–150.

Coleman, James S. 1990. *Foundations of social theory*. Cambridge; London: The Belknap Press of Harvard University Press.

Cook, Philip J. 1980. “Research in criminal deterrence: Laying the groundwork for the second decade.” *Crime and Justice: An Annual Review of Research* 2.

Dasgupta, Partha. 1988. “Trust as a commodity.” In *Trust: Making and Breaking Cooperative Relations*, volume 4, pp. 49–72. Oxford: Blackwell.

Diekmann, Andreas, Ben Jann, Wojtek Przepiorka, and Stefan Wehrli. 2014. “Reputation formation and the evolution of cooperation in anonymous online markets.” *American sociological review* 79:65–85.

Diekmann, Andreas, Wojtek Przepiorka, and Heiko Rauhut. 2015. “Lifting the veil of ignorance: An experiment on the contagiousness of norm violations.” *Rationality and Society* .

Diekmann, Andreas and Thomas Voss. 2004. “Die Theorie rationalen Handelns. Stand und Perspektiven.” In *Rational-Choice-Theorie in den Sozialwissenschaften : Anwendungen und Probleme*, edited by Andreas Diekmann and Thomas Voss, Scientia Nova. M??nchen: Oldenbourg. hrsg. von Andreas Diekmann und Thomas Voss.

Dixit, Avinash. 2011. “A game-theoretic perspective on Diego Gambetta’s Codes of the Underworld.” *Global Crime* 12:134–145.

Dixit, Avinash K. and Susan Skeath. 2004. *Games of strategy*. New York: W.W. Norton, 2nd edition. Avinash Dixit, Susan Skeath. ill. ; 26 cm.

Doob, Anthony N. and Cheryl M. Webster. 2003. “Sentence Severity and Crime: Accepting the Null Hypothesis.” *Crime and Justice. A Review of Research* 28:143–195.

Eaton, B.Curtis and Jean-Francois Wen. 2008. “Myopic deterrence policies and the instability of equilibria.” *Journal of Economic Behavior & Organization* 65:609–624.

Fehr, Ernst and Simon Gächter. 2002. “Altruistic Punishment in Humans.” *Nature* 415:137–140.

Fehr, Ernst and Herbert Gintis. 2007. “Human Motivation and Social Cooperation: Experimental and Analytical Foundations.” *Annual Review of Sociology* 33:43–64.

Fehr, Ernst and Klaus M. Schmidt. 1999. "A theory of fairness, competition, and cooperation." *Quarterly Journal of Economics* 114:817–868.

Friedman, David. 1995. "Rational criminals and profit–maximizing police. The economic analysis of law and law enforcement." In *The new economics of behavior*, edited by Mariano Tommasi and Kathryn Ierulli, pp. 43–58. Cambridge: Cambridge University Press.

Fudenberg, Drew and David K. Levine. 1998. *The Theory of Learning in Games*. Cambridge, MA: MIT Press.

Gambetta, Diego. 2009a. *Codes of the underworld: How criminals communicate*. Princeton University Press.

Gambetta, D. 2009b. "Signaling." *The Oxford Handbook of Analytical Sociology* pp. 168–194.

Gambetta, Diego and Heather Hamill. 2005. *Streetwise: How Taxi Drivers Establish Customer's Trustworthiness*. Russell Sage Foundation.

Gigerenzer, Gerd and Daniel G. Goldstein. 1996. "Reasoning the fast and frugal way: Models of bounded rationality." *Psychological Review* 103:650–669.

Gintis, Herbert. 2000. *Game theory evolving: A problem-centered introduction to modeling strategic behavior*. Princeton, NJ: Princeton University Press.

Gintis, Herbert. 2007. "A framework for the unification of the behavioral sciences." *Behavioral and brain sciences* 30:1–61.

Graetz, Michael J, Jennifer F Reinganum, and Louis L Wilde. 1986. "The tax compliance game: Toward an interactive theory of law enforcement." *Journal of Law, Economics, & Organization* pp. 1–32.

Heckathorn, Douglas D. 1989. "Collective Action and the Second-Order Free-Rider Problem." *Rationality and Society* 1:78–100.

Hedström, P. and P. Bearman. 2009. *The Oxford handbook of analytical sociology*. Oxford University Press, USA.

Holler, Manfred J. 1990. "The unprofitability of mixed-strategy equilibria in two-person games: A second folk-theorem." *Economics Letters* 32:319–323.

Holler, Manfred J. 1993. “Fighting pollution when decisions are strategic.” *Public Choice* 76:347–356.

Horne, Christine and Heiko Rauhut. 2013. “Using Laboratory Experiments to Study Law and Crime.” *Quality and Quantity* 47:1639–1655.

Jackson, Matthew O and Asher Wolinsky. 1996. “A strategic model of social and economic networks.” *Journal of economic theory* 71:44–74.

Kahan, D. M. 1997. “Social influence, social meaning, and deterrence.” *Virginia Law Review* 83:349–395.

Levitt, Steven D. 2002. “Deterrence.” In *Crime: Public Policies for Crime Control*, edited by James Q Wilson and Joan Petersilia, pp. 435–450. Institute for Contemporary Studies Press.

Lochner, Lance. 2007. “Individual perceptions of the criminal justice system.” *American Economic Review* 97:444–460.

Macy, Michael and Andreas Flache. 2009. “Social dynamics from the bottom up. Agent-based models of social interaction.” In *The Oxford Handbook of Analytical Sociology*. Oxford University Press.

Macy, Michael W. 1991. “Learning to Cooperate: Stochastic and Tacit Collusion in Social Exchange.” *American Journal of Sociology* 97:808–843.

Macy, M. W. 1993. “Backward-Looking Social-Control.” *American Sociological Review* 58:819–836.

Macy, Michael W. and Andreas Flache. 2002. “Learning Dynamics in Social Dilemmas.” *Proc Natl Acad Sci USA* 99:7229–7236.

McKelvey, Richard D. and Thomas R. Palfrey. 1995. “Quantal Response Equilibria for Normal Form Games.” *Games and Economic Behavior* 10:6 – 38.

Murphy, Ryan O. and Kurt A. Ackermann. 2013. “Social Value Orientation: Theoretical and Measurement Issues in the Study of Social Preferences.” *Personality and Social Psychology Review* Online First:1–29.

Nagin, Daniel S. 1998. “Criminal Deterrence Research at the Outset of the Twenty-First Century.” *Crime and Justice. A Review of Research* 23:1–42.

Nash, John. 1951. "Non-cooperative games." *The Annals of Mathematics* 2:286–295.

Nosenzo, Daniele, Theo Offerman, Martin Sefton, and Ailko van der Veen. 2012. "Encouraging Compliance: Bonuses versus Fines in Inspection Games." *CeDEx Discussion Paper Series* pp. 1–30.

Przepiorka, Wojtek. 2010. "Diego Gambetta: Codes of the Underworld: How Criminals Communicate." *Rationality, Markets and Morals* 1:9–11.

Raub, Werner. 2009. "Commitments by hostage posting." *Perspectives in Moral Science* pp. 207–225.

Raub, Werner and Vincent Buskens. 2004. "Spieltheoretische Modellierungen und empirische Anwendungen in der Soziologie." *Kölner Zeitschrift für Soziologie und Sozialpsychologie* 44:560–598.

Rauhut, Heiko. 2009. "Higher punishment, less control? Experimental evidence on the inspection game." *Rationality and Society* 21:359–392.

Rauhut, Heiko. 2015. "Stronger inspection incentives, less crime? Further experimental evidence on inspection games." *Rationality and Society* 27:1–41.

Rauhut, Heiko and Silvana Jud. 2014. "Avoiding detection or reciprocating norm violations? An experimental comparison of self- and other-regarding mechanisms for norm adherence." *Soziale Welt* 65:153–183.

Rauhut, Heiko and Marcel Junker. 2009. "Punishment deters crime because humans are bounded in their strategic decision-making." *Journal of Artificial Social Systems and Societies (JASSS)* 12.

Rauhut, Heiko and Fabian Winter. 2012. "On the Validity of Laboratory Research in the Political and Social Sciences. The Example of Crime and Punishment." In *Experimental Political Science: Principles and Practices*, edited by Bernhard Kittel, Wolfgang Luhan, and Rebecca Morton, pp. 209–232. Palgrave Research Methods Series.

Sampson, Robert J. 2000. "Whither the sociological study of crime." *Annual Review of Sociology* 26:711–714.

Schelling, Thomas C. 1960. *The strategy of conflict*. Cambridge,: Harvard University Press. illus. 22 cm.

Simon, Herbert A. 1955. "A Behavioral Model of Rational Choice." *The Quarterly Journal of Economics* 69:99–118.

Tambe, Milind. 2011. *Security and game theory: algorithms, deployed systems, lessons learned*. Cambridge University Press.

Todd, Peter M. and Gerd Gigerenzer. 2000. "Precis of Simple heuristics that make us smart." *Behavioral And Brain Sciences* 23:727–780.

Tsebelis, George. 1989. "The Abuse of Probability in Political Analysis: The Robinson Crusoe Fallacy." *American Political Science Review* 1:77–91.

Tsebelis, George. 1990. "Penalty Has No Impact on Crime. A Game Theoretic Analysis." *Rationality and Society* 2:255–286.

Van Lange, P.A.M. 1999. "The pursuit of joint outcomes and equality in outcomes: An integrative model of social value orientation." *Journal of Personality and Social Psychology* 77:337.

Voss, Thomas. 2001. "Game-Theoretical Perspectives on the Emergence of Social Norms." In *Social norms*, edited by Michael Hechter and Karl-Dieter Opp. New York: Rusell Sage Foundation.

Voss, Thomas. 2006. "Game theory." In *International encyclopedia of economic sociology*, edited by Jens Beckert and Milan Zafirovski, pp. 296–299. Routledge (Taylor and Francis).

Williams, K. R. and R. Hawkins. 1986. "Perceptual Research On General Deterrence - A Critical-Review." *Law & Society Review* 20:545–572.

Wittman, Donald. 1985. "Counter-intuitive results in game theory." *European Journal of Political Economy* 1:77 – 89.