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Dilemma
- A Game Theoretic Approach to Addiction -

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Alcoholics Anonymous encourages its members, people who have difficulties to control their alcohol consumption, to refrain from drinking on the basis of "one day at the time". Meanwhile, we know that one more or one less drink will not determine whether a person becomes addicted. What are the incentives facing this person when he decides on whether to drink one more glass or to remain sober?

This thesis models a single decision-maker as represented by an infinite number of agents, each making one independent choice. Addictions, regardless of whether they refer to alcohol, cigarettes, drugs, work, eating, music, television, a certain standard of living or any other action, are considered in terms of tail events. Such an approach to addiction accommodates a number of counterintuitive phenomena and shows that addicts face important decision dilemmas with regard to their consumption.

The results call for a distinction between optimizing a single action and maximizing lifetime utility. In order to avoid dilemmas, and especially evade welfare inferior outcomes, some self-imposed rules and outsider interventions are suggested.

KEYWORDS: Addiction, coordination games, countable infinite player sets, tail events, dominant strategies, payoff dominance, lack of Nash equilibrium.

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1. Introduction

Members of Alcoholics Anonymous, workaholics, cigarette smokers and piano players have something in common. They often need to decide on whether they should drink one more glass, work one more hour, smoke one more cigarette or play the piano one more time. When that single "one more" does not determine whether the person becomes an alcoholic, workaholic, cigarette addict or pianist, an interesting decision-making problem arises. How does such a person make choices? What are the incentives behind each choice? If he optimizes every single decision, will he be maximizing his lifetime utility as well? Is it evident for a rational person to decide what to choose next time he is offered another glass of wine, hour of work, cigarette or minute of piano playing?

1.1 Game Theory and Infinite Player Sets

In order to analyze these questions, we will use game theory, which has during the last few decades been widely used in economics as well as in neighbouring disciplines and enabled progress in clarifying the nature of strategic interaction. A game in its simplest strategic form typically exhibits a set of players, a set of strategies (choices that each player can make), and a set of payoffs that indicate the utility that each player receives if a particular combination of strategies is chosen.

Many well-known games[1] model interaction between two players, although there are various extensions with more than two players as well. Infinite player sets, on the other hand, are rather unusual in game theory and may seem unrealistic at a first glance. Yet, a closer look at existing theories and models in economics reveals that the assumption of infinite players is already being used extensively. In industrial organization and general equilibrium theory economists usually assume an infinite set of players when rationalizing, for instance, the model of perfect competition. However, these models typically assume a continuum of players where each participant's influence on payoffs is negligible (Aumann, 1964). Given the fact that players can be counted, an alternative and somewhat more realistic assumption would be to consider a countably infinite set instead.

[1] Such as for example the prisoner's dilemma, the battle of the sexes, matching pennies, the minimum effort game, and the traveler's dilemma.

They can simply be labeled 1, 2, 3…making the player set equal to the set $\mathbb{N}$ of positive integers. In contrast to a continuum of players, the assumption of a countably infinite set implies that each payer may have an effect on payoffs and signifies an interesting starting point for analyses of games with a large number of participants where individual influences cannot be ignored.

There are several motivations for games with a countably infinite set of players. Basu (1994) argues that if current and future generations are considered, the number of people may well be infinite. Apart from the number of players, infinity can also refer to generations, as in the model of overlapping generations' economies where each generation has a finite lifetime.[2] Milchtaich (2004) models infinite games when the population is finite but the upper bound uncertain and suggests internet auctions and housing markets as potential areas of application. His idea is analogous to the one underlying infinitely repeated games, where the players at the end of each round believe there is yet another round to be played. An important distinction has to be highlighted here between a setting with infinitely repeated games and the one with infinite player sets. In the former, there are only finitely many players, but each makes infinitely many choices and can let their choices depend on what happened in earlier rounds of play. In the latter, there are infinitely many players, but each makes only one independent choice.[3] Another interesting way of using infinite player sets, suggested by Basu (2000), is to consider a single decision-maker with an uncertain lifetime. At every date *t* there is a probability $\delta<1$ that he will live one more day.[4] This implies infinitely many decision points for the player if we assume that he at each day will decide whether to take a certain decision or not. Moreover, if these decisions are assumed to be independent of past and future decisions, the common way to model this is by representing the single decision-maker by an infinite number of agents (one for each decision), all of whom have the same utility function. This is the interpretation behind most of the examples in this thesis.

[2] Asheim and Tungodden (2004), for example, assume infinite generations when modelling distributional conflicts.

[3] Infinitely repeated games are often illustrated in extensive form in order to highlight the choices in previous games, while a game with infinite number of players is sufficient to demonstrate in its normal form, since it is only played once.

[4] Since it is assumed that the person does not know when he will die, this is considered as an infinite horizon problem and the δ appears like a discount factor.

Finally, it is also possible to consider a limited amount of time, for example a year, and allow the player to take infinitely many decisions during that year.[5] Regardless of infinity referring to the number of players, lifetime of a single person or the number of decision points within a limited time, the logic and way of modeling can be the same in all three interpretations.

Coordination games, which are the only games considered in this thesis, have several characteristics that make them rather interesting in many areas of economic research. In comparison with other strategic situations, coordination games do not assume conflicts of interest among players. Instead, players are assumed to have common goals and consequently maximize the same utility function.

Coordination games with a countably infinite set of players allow a number of practically relevant phenomena that cannot occur in finite settings. For notational convenience, these games will henceforth be called infinite (in the case of countable infinite player sets) and finite (in the case of finite player sets). Basu (1994) introduced an infinite game which shows that, in contrast to finite games, the dominant strategy equilibria need not be Pareto optimal. He applies the game to the use of language and argues that if we made excessive use of language in a parasitical way, that is, telling lies for strategic purposes, then language would lose much of its value even as a normal instrument of communication. Inspired by these results, Voorneveld (2007) establishes the possibility of three additional phenomena that can only occur in infinite games. First, his models demonstrate that in coordination problems the best outcome may occur if all players choose a weakly dominated strategy, whereas the worst outcome results from everyone choosing a dominant strategy. Second, seemingly identical games (in terms of consequences of individual players' decisions) may nevertheless have different Pareto dominant equilibria. Third, he illustrates that Nash equilibria may not exist in infinite games, not even in mixed strategies.

Since such phenomena are impossible in standard finite models and appear rather puzzling and counter-intuitive to most people, one of the main goals of this thesis will be to highlight their applicability and relevance to real-life decisions.

[5] Arntzenius et al. (2004), for example, resolve paradoxes entailing infinite choices.

1.2 Addictions Modeled as Infinite Coordination Games and Tail Events

In this thesis, infinite coordination games will be applied to addictions and habitual behaviors, as these are assumed to involve considerable repetitions of a certain action and could be modeled as an infinite decision problem. The interpretation of a countably infinite set of players used will be the one with a single decision-maker represented by infinitely many agents.[6] Each agent is taking one decision, but the utility function is common for all, since they all represent the same individual. Furthermore, addictions and habits are chosen due to their behavioral appropriateness when illustrating a tail event, which according to Voorneveld (2007) is the mathematical reason for the existence of these phenomena in infinite games. The essential feature of a tail event, namely that no action of a single player[7] or decision determine which tail event will occur, suits behaviors of addicts rather well; one more or one less intake of a certain good generally does not determine whether a person becomes addicted or not.

1.3 Previous Research on Addiction

As Becker and Murphy (1988) have argued, people can get addicted to not only cigarettes, alcohol, and cocaine, but also to work, eating, music, television, their standard of living, other people, religion and many other activities. Stigler and Becker (1977) distinguish between beneficial and harmful addictions according to whether consumption of the good has a positive or negative effect on utility.[8] Depending on the context in which it is being analyzed, addiction has been defined in various ways. Central to the definition used in this thesis is that an addiction is a strong *habit* and therefore a behavioral pattern done often and easily. Moreover, addiction involves craving and is difficult to stop: despite attempts at abstention of varying success, a real addict eventually returns to consuming the addictive substance.

One of the central axioms of economics and therefore also one of the bases in game theoretic analyses is the assumption of rational behavior on the part of individuals. A person is considered rational if he, given the information available to him, chooses the

[6] Player and agent will be used synonymously in this thesis.
[7] Or even finite number of players.
[8] Although most researchers agree on the existence of harmful as well as beneficial addictions, Tomer (2001) for example, rejects the existence of the latter kind.

action that maximizes his utility. Addiction has also been subject to analyses using the rational choice framework. In a rather path breaking article, Becker and Murphy (1988)[9] explored the theory of rational addiction in which they explain addictive behavior in terms of utility-maximizing consumers with stable preferences. According to this model, consumers anticipate the addiction and health consequences of their decisions and choose to adopt addictive behavior because the anticipated benefits outweigh the costs. Although several empirical findings[10] are consistent with Becker and Murphy's (1988) key prediction that current consumption depends on future consumption, their theory has also been questioned on several grounds. Gruber and Köszegi (2001) argue that forward-looking behavior does not imply time consistent preferences. In modifying Becker and Murphy's (1988) model by allowing an individual's preferences to be time inconsistent, they are able to obtain the same positive relationship between current consumption and future consumption.[11] Another modification to the theory of rational addiction is suggested by Orphanides and Zervos (1995) who incorporate learning in their model. The best known alternative theories of behavior in the consumption of addictives are those associated with the self-control literature. Akerlof (1991) argues that the model of forward-looking, utility maximizing rational behavior doesn't accurately describe the way in which individuals decide on, for example, drug intake. According to him, most addicts recognize that the long-run costs of their addiction exceed its benefits. Yet, they procrastinate their decision to end their consumption, as the present costs are unduly salient in comparison with future costs. Schelling (1984, 1985) has suggested a similar approach on addiction and emphasized the difficulty in abiding by self-imposed rules.

This thesis assumes rational and utility maximizing individuals with stable preferences as in Becker and Murphy (1988), but shows that dynamic inconsistencies and preference reversals can arise anyway. Although several researchers have analyzed the economics of addiction, no one apart from Basu (1994, 2000) and Voorneveld (2007) has, to my knowledge, analyzed the decision problems facing individuals with habits or

[9] See also Stigler and Becker (1977), Becker et al. (1991), and Becker (1996).

[10] For example, Chaloupka (1990, 1991) uses micro data, Grossmann and Chaloupka (1998) panel data, and Perkurinen (1991), Keeler et al. (1993), Becker et al. (1994) and Bardsley and Olekalns (1998) use time series data to study cigarette smoking behavior in the context of the Becker and Murphy (1988) model. Their findings are in line with the key predictions of Becker and Murphy's (1988) model.

[11] See also Bretteville-Jensen (1999) for a discussion on time inconsistent preferences in connection with addiction.

addictions using a purely game theory framework including infinite coordination games. While the former introduced only one problem facing addicted decision-makers, and the latter keeps a more technical approach on three phenomena, this thesis combines the results from the two researchers and keeps a practical approach to four dilemmas that individuals can find themselves in and suggests practical solutions to them. Therefore, this thesis contributes to the literature on game theory, where infinite coordination games are rather unusual, and presents new ways of analyzing addictive behavior. Furthermore, it provides a new practical area of application for mathematical tools as tail events. Another major contribution is to the growing literature on welfare economics and equilibrium selection problems.

Rather than providing any clear-cut results, this thesis highlights the conflict between intuition and game theoretic reasoning facing seemingly rational individuals and shows that some simple rules or interventions could help to avoid undesirable outcomes. The results also shed light on the practical relevance of infinite coordination games and demonstrate the necessity to distinguish between optimizing actions and maximizing lifetime utility.

The remainder of this thesis is organized as follows. Section 2 provides the necessary definitions for the subsequent formal analyses. Sections 3, 4, 5, and 6 each highlight a particular dilemma facing a person who has to decide on whether to consume a certain addictive product or not. Each one of these sections will first describe the phenomenon, then go on to explain why its occurrence in finite games is impossible and finally demonstrate why it is possible in infinite games by illustrating a practical example of the dilemma. Section 7 proposes ways to avoid the dilemmas and Section 8 consists of a concluding discussion.

2. Definitions and Preliminaries

This section defines the general game and the assumptions being used throughout this thesis. In order to elucidate the consequent reasoning, some standard concepts from game theory and mathematics are presented.

2.1 The General Setting

A game is a tuple[12] $G = \langle N, (A_i)_{i \in N}, (u_i)_{i \in N} \rangle$ where

- N is a nonempty, finite or countably infinite set of players,
- each player $i \in N$ has a nonempty, finite set of pure strategies, A_i,
- $u_i : \times_{i \in N} A_i \to \mathbb{R}$ is a von Neumann-Morgenstern[13] utility function.[14]

The game *G* is a coordination game if all players get the same utility, i.e. if there exists a function $u : A \to \mathbb{R}$ such that $u_i = u$ for all $i \in N$. As in the standard economics model of rational choice, we assume that preferences are well defined and that individuals rationally maximize utility.[15] If all individuals have same utility function, one could think of this game as individuals adhering to utilitarianism, which is a moral judgement according to which each person should choose the action, from those available to him, that maximizes the total utility or happiness of all human beings (Basu 2000). As mentioned earlier, this thesis will consider a single person represented by an infinite number of agents, each making one independent decision. Thus, the analysis is limited to non-cooperative games. Although each agent makes one independent decision, they all represent the same single individual and therefore maximize the same utility function.

[12] A tuple is a set of elements in which the element positions are ordered (Rasmusen, 2007).

[13] A von Neumann-Morgenstern utility function expresses the desirability of alternatives in terms of their expected utility.

[14] We stay as close as possible to the standard settings of Nash (1951). The only point of difference is the assumption of an infinite set of players.

[15] Economists usually mean that preferences are well defined if they are *complete* in the sense that one bundle can be compared to another, and *transitive* in the sense that if bundle a is preferred to bundle b, which is preferred to c, then a is also preferred to c. Furthermore, well defined preferences should be *reflexive* which means that individuals must be indifferent between identical bundles, and *monotone* in the sense that individuals, *ceteris paribus*, prefer more of any bundle than less. By including the assumptions of *convexity* and *continuity*, it can be proven that a utility function exists. A presentation of these conditions can be found in, for example, Varian (1992).

We can model the game as an infinite game because we assume that the individual in consideration does not know when he will die. Every day, there is a chance that he will live yet another day. It is common knowledge that each of these agents are rational, that is, each one chooses the action that maximizes his and thereby everyone else's utility given his subjective beliefs. Furthermore, we assume that the strategies and payoffs available to the players are common knowledge in the sense that each player knows his own payoffs and strategies, and the other players' payoffs and strategies. All payers know that the other players know this, and so on. Thus, there is no asymmetry in information.

All utility functions in the subsequent chapters have a discounting rate of 0.5, are only illustrative and, for mathematical convenience, kept as simple as possible.[16]

When comparing two games we assume von Neumann-Morgenstern equivalence (vNM-equivalence), following the definitions in Morris and Ui (2004). Two games are vNM-equivalent if, for each player, the payoff function in one game is equal to a constant times the payoff function in the other game, plus a function that depends only on the opponents' strategies. Two games are vNM-equivalent if and only if, for each player i, there is a constant $w_i>0$ such that the ratio of payoff differences from switching between one strategy to another strategy is always w_i. The constant w_i is thus independent of the strategies being compared. More formally,

A game g is vNM-equivalent to $g' = (g'_i)_{i\in N}$ if, for each $i \in N$, there exist a positive constant $w_i > 0$ and a function $Q_i : A_{-i} \to \mathbb{R}$ such that

$$g_i(a_i,\cdot) = w_i g'_i(a_i,\cdot) + Q_i(\cdot)$$

for all $a_i \in A_i$.

Thus, if g is vNM-equivalent to g', then

$$g_i(a_i,\cdot) - g_i(a'_i,\cdot) = w_i\left[g'_i(a_i,\cdot) - g'_i(a'_i,\cdot)\right]$$

for all $a_i, a'_i \in A_i$. Conversely, if this is true, then a function $Q_i : A_{-i} \to \mathbb{R}$ such that

$$Q_i(\cdot) = g_i(a_i,\cdot) - w_i g'_i(a_i,\cdot)$$

is well defined, and thus g is vNM-equivalent to g'.

[16] The emphasis is on the phenomena they illustrate. See, for instance, Basu and Mitra (2007) for symmetric aggregations of utility streams.

2.2 Standard Concepts from Game Theory

By definition, a strategy profile a^* is a Nash equilibrium if no player has incentive to deviate from his strategy given the behavior of the other players (Nash, 1951). Formally,

$$\forall i, \quad u_i(a_i^*, a_{-i}^*) \geq u_i(a_i^t, a_{-i}^*),\ \forall a_i^t .$$

Nash (1950) also argues that in the n-player strategic game $G = \{A_1,..., A_n; u_1,..., u_n\}$, if n is finite and A_i is finite for every *i*, then there exists at least one Nash equilibrium, possibly involving mixed strategies. In the strategic game $G = \{A_1,..., A_n; u_1,..., u_n\}$, suppose $A_i = \{a_{i1},..., a_{iK}\}$. Then a mixed strategy for player *i* is a probability distribution $p_i = (p_{i1},..., p_{iK})$, where $0 \leq p_{iK} \leq 1$ for k=1,…,K and $p_{i1}+\ldots+p_{iK}=1$.

Since no player alone determines the payoffs, it must carefully decide which strategy to play. For example, the strategy a_i^* is a strictly dominant strategy if it is a player's strictly best response to any feasible strategy that the others might play in the sense that whatever strategy the other players play, his payoff is highest with a_i^*. More formally,

$$\forall a_{-i},\ \forall a_i^t \neq a_i^*: \qquad u_i(a_i^*, a_{-i}) > u_i(a_i^t, a_{-i}).$$

Similarly, strategy a_i^* is a weakly dominant strategy if it is always as good as any other strategy $a_i^t \neq a_i^*$, i.e.,

$$\forall a_{-i},\ \forall a_i^t \neq a_i^*: \qquad u_i(a_i^*, a_{-i}) \geq u_i(a_i^t, a_{-i}),$$

and sometimes strictly better：

$$\forall a_i^t \neq a_i^* \exists a_{-i}: \qquad u_i(a_i^*, a_{-i}) > u_i(a_i^t, a_{-i}).$$

Logically, it also follows that the strategy a_i^t is strictly dominated if there exists $a_i^{tt} \in A_i$ such that

$$\forall a_{-i}: \qquad u_i(a_i^{tt}, a_{-i}) > u_i(a_i^t, a_{-i}).$$

Correspondingly, strategy a_i^t is weakly dominated if there exists some other strategy a_i^{tt} for player *i* which is always at least as good as a_i^t:

$$\forall a_{-i}: \qquad u_i(a_i^{tt}, a_{-i}) \geq u_i(a_i^t, a_{-i}),$$

and sometimes strictly better:

$$\exists a_{-i}: \qquad u_i\left(a_i'', a_{-i}\right) > u_i\left(a_i', a_{-i}\right).$$

Dominant strategy equilibrium is a strategy profile consisting of each player's dominant strategy. Dominance is important because, if payoffs are correctly specified and players care only about their own utility, then there is no good reason to violate a strict dominance (Camerer 2003).

In order to compare the outcomes from different strategies, we use some standard notions from welfare economics, namely those of Pareto dominance and Pareto optimality. If outcome X strongly Pareto dominates outcome Y, then all players have higher utility under outcome X. If outcome X weakly Pareto dominates outcome Y, some players have higher utility under X, and no player has lower utility. A change from a Pareto optimal outcome implies that no player gains without another player loosing.

2.3 Kolmogorov's Zero-One Law and Tail Events

Kolmogorov's zero-one law, mostly used in probability theory, specifies that certain type of events, so called tail events, will occur with probability zero or one (Williams, 1991). This means that a tail event will either almost surely not happen or almost surely happen. No probability in between is possible. Tail events are defined in terms of infinite sequences of independent stochastic variables. In the subsequent games, players' individual action choices are random variables. Assume that the player set is $\mathbb{N}$. As each player $i \in \mathbb{N}$ has a finite set A_i of actions, we can label them and assume, without loss of generality, that A_i is a finite subset of $\mathbb{R}$. All games will use $A_i = \{0,1\}$. For each $i \in \mathbb{N}$, let $X_i : A \to \mathbb{R}$ be the random variable pointing out the action of player $i : X_i(a) = a_i$ for each $a \in A$. The choice of an action sequence is an infinite vector of zeroes and ones. By definition, whether a tail event occurs is independent of the realization of finitely many of the X_i's: only tails matter. For example, the event that the series $\sum_{k=1}^{\infty} X_k$ converges is a tail event. In contrast, the event that the sum to which it converges is more than one, is not a tail event, since it is not independent of the value of, for instance, X_1. [17]

Addictions in this thesis are defined in terms of tail events, that is, consuming one more or one less unit of a certain good will not determine whether you get addicted to it. However, a person is defined as addicted if it keeps repeating the action infinitely often.

3. Addiction – Self-Defeating Behavior?

Is it logically possible to end up in a situation inferior to your original situation, if you, in every action, have been in pursuit of utility enhancement? With this question in mind, I introduce the first paradox of this thesis, first formally, and thereafter by imagining a single sad individual who is in search of happiness by using addictive substances.[18]

3.1 Game 1

Basu (1994) has shown that there are games where

(a) all players have the same payoff function U, which means that there are no conflicts of interest,

(b) each player i has a strictly dominant strategy a_i^*,

(c) yet each player i (and hence everyone) is better off if no one chooses the dominant strategy than if everyone chooses it, as in the unique Nash equilibrium.[19]

If, and only if, the number of players is infinite can 3.1a to 3.1c hold simultaneously. To see this, suppose there are $n \in \mathbb{N}$ players in the game. Start from an arbitrary strategy profile $a = (a_1, ..., a_n)$ and let each player unilaterally switch to the strictly dominant

[17] Another way of illustrating a tail event is to think of an infinite sequence of coin-tosses. The probability that a sequence of 10 consecutive heads occurs infinitely many times, is a tail event, while the event that the first coin is a head is not a tail event.

[18] Happiness and utility are used synonymously throughout this thesis.

[19] Basu (1994) calls a game satisfying property (a) to (c) the Waterfall game, as it is reminiscent of the Dutch graphic artist Maurits Cornelis Escher's 1961 lithography of a waterfall. Escher is known for his mathematically inspired impossible pictures, and in Waterfall he illustrates an apparent paradox where the water from the base of a waterfall appears to flow downhill but ends up on top. See Bool *et al* (1992) for illustrations of Escher's work.

strategy. Every such switch raises the payoff for all players and since we can, in finite number of switches, go from the case where no one chooses the dominant strategy to the case where everyone chooses it, it follows that payoff must be higher in the latter case;

$$U(a_1,...,a_n) < U(a_1^*, a_2..., a_n) < \cdots < U(a_1^*,...,a_n^*).$$

Therefore, if 3.1a and 3.1b hold in finite games, 3.1c cannot be true (see Appendix 1 for a matrix illustration of a finite coordination game with a strictly dominant strategy). Consequently, the answer to the question introducing this section is a straightforward no for finite coordination games. Consistent with standard game theory and the idea of dominance, choosing a dominant strategy cannot make a player worse off in finite games.

3.2 In Pursuit of Utility Enhancement

The following example clarifies why the properties 3.1a to 3.1c can hold simultaneously in infinite coordination games and thereby explains why it is logically possible to end up in an inferior situation even though one has, in every action, been in pursuit of utility enhancement.

Example 1. Assume each player $i \in \mathbb{N}$ has two pure strategies, 0 and 1, and payoff function $U : \times_{j\in N} \{0,1\} \to \mathbb{R}$ defined, for each $a \in \times_{j\in N} \{0,1\}$, by

$$U(a) = \begin{cases} \sum_{j\in N} a_j \cdot 2^{-j} & \text{if} \quad \sum_{j\in N} a_j < \infty, \\ -2 + \sum_{j\in N} a_j \cdot 2^{-j} & \text{if} \quad \sum_{j\in N} a_j = \infty. \end{cases}$$

Think of this game as representing a sequence of independent choices of a single decision-maker on whether to use (action 1) or abstain from using (action 0) a certain addictive substance.[20] Assume that these independent choices are made by agents all having the same utility function *U*. Then, property 3.1a holds. The actions chosen for all the other days remaining the same, if the person decides to consume the substance today, he will be better off as the utility will increase by $2^{-i}>0$. Thus, action 1 is his strictly dominant strategy and property 3.1b is satisfied. As Tomer (2001) notes, drugs yield artificial rewards as consolidation, relief, feeling of balance otherwise missing, energy,

[20] Henceforth, if player *i* chooses action 1, this means that he chooses to consume the addictive substance at the point where it is his turn to decide, whereas action 0 denotes that he rejects the addictive substance.

and other kind of temporary effects. Furthermore, Brown (1986, p.636) describes this phenomenon in the following way.

> Addictions like smoking a cigarette, having a drink, eating a candy bar, and working overtime to ‘catch up’ all lead to immediate and certain gratifications, whereas their bad consequences are remote in time…

Property 3.1c asserts that choosing to consume the addictive substance every day leaves the person worse off than not having consumed the substance at any time at all. Most people would agree on this statement, and it has been noted that an excessive and prolonged use of alcohol, for example, is expected to cause cirrhosis of the liver and damage the family and work relationships, and may even lead to death (Tomer, 2001; Ramstedt, 2001).

Hence, in the unique equilibrium of the game, each agent chooses action 1. To show that property 3.1.c holds, notice that this equilibrium gives a payoff of -1, whereas not using the substance at all gives a payoff of 0:

$$U(1,1,\ldots) = -1 < 0 = U(0,0,\ldots).$$

Figure 1 illustrates that for each player *i*, strategy 1 dominates 0. In the unique equilibrium of the game, player *i* chooses 1 and so do infinitely many others. Thus, there is no Pareto dominant Nash equilibrium in this infinite game. This conclusion reminds of the one drawn in the standard Prisoner’s dilemma.

Figure 1. Infinite Coordination Game as Prisoner's Dilemma

		Finitely many others choose 1	Infinitely many others choose 1
Player *i*	Choose 0	$0+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$	$0-2+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$
	Choose 1	$2^{-i}+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$	$2^{-i}-2+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$

Note: The arrows indicate the dominant strategies and encircled is the unique Nash equilibrium.

Even though players are better off in the case when no one chooses strategy 1, they are not happy, since the strategy profile is not an equilibrium. In fact, several studies[21] have suggested that the beginning and resumption of harmful addictions, such as smoking, heavy drinking, gambling, cocaine use, and overeating, are often stimulated by divorce, unemployment, death of a loved one, and other stressful events (Becker and Murphy, 1988). Robins *et al*. (1980) note that due to the extraordinary stress during the Vietnam War, many soldiers became permanently addicted to drugs. Although most veterans did end their addiction to drugs after returning to the United States, many did not, and others shifted from dependence on drugs to dependence on alcohol. Thus, this game emphasizes a harmful addiction and especially the idea that substances yielding a temporary happiness can tempt a person who is sad and in search of happiness.

Moreover, it highlights the difficulty in ending an addiction and the feeling of being in a suboptimal point all the time. At each decision, the person feels that an additional unit of the addictive commodity will make him better off. Even if this person intends to stop his consumption some day, he will have an incentive to procrastinate the last intake and therefore risk not quitting his habit at all. Indeed, this is similar to the reasoning in Akerlof (1991), yet what is suggested here occurs despite time consistent preferences and without undue salience of present costs.[22]

Interestingly, this game also sheds light on an important theory in welfare economics, namely the theory of the invisible hand. According to the latter, every individual working in his individual interest may lead to an outcome which is optimal for the group (Basu, 1994). What has been presented in this section suggests the opposite; a suboptimal outcome may result, despite each individual's strive to increase utility. Therefore, this game illustrates a critique to the theory of the invisible hand and to the standard model of perfect competition. Furthermore, the example used in this section shows that, in addition to analyses of societies, the theory of the invisible hand can be used when analyzing the welfare of a single decision-maker. More precisely, it shows

[21] See the studies reviewed in Peele (1985).

[22] Akerlof's (1991) model assumes tiny irrationality and time inconsistent preferences and therefore differs from the assumptions underlying the games in this thesis.

that an individual may make perfectly rational decisions, when considering each decision at a time, but still regret the totality of the decisions.[23]

4. Worse May be Best and Better May be Worst

Could you reach your most desired outcome by constantly choosing a strategy that is as good as or worse than the other strategy? Concurrently, could a recurrent choice of a relatively better strategy make you end up in the least desired outcome? By altering the strict dominance in the previous section to a weak dominance, this section illustrates the possibility of answering yes to both these questions.

4.1 Game 2

Voorneveld (2007) establishes the existence of games where

(a) all players have the same payoff function,

(b) each player has a weakly dominant strategy,

(c) yet, everyone choosing the weakly dominant strategy leads to the worst outcome of the game while everyone choosing the dominated strategy yields the highest payoff possible.

In a finite coordination game, property 4.1c cannot be true if 4.1a and 4.1b hold (see Appendix 2 for a presentation of a finite coordination game with a weakly dominant strategy). The reason is similar to the one presented in the previous section. It follows from the definition of a weakly dominant strategy that choosing it is always as good as or better than any other feasible strategy that the other players can choose. Therefore, the worst possible outcome of a finite game cannot be achieved by choosing such a strategy. Similarly, the Pareto optimal outcome of a finite game cannot be achieved when all players choose the weakly dominated strategy.

[23] This is similar to the large numbers argument which states that each class of actions could be morally justifiable, whereas the whole class of actions may be morally unacceptable (Basu, 2006).

4.2 Different Stages of Consumption

The following example illustrates a harmful addiction, but in contrast to the previous example, the person facing this game starts his consumption despite initially being happy.

Example 2. Suppose each player $i \in \mathbb{N}$ has two pure strategies, 0 and 1, and payoff function $U : \times_{j \in N} \{0,1\} \to \mathbb{R}$ defined, for each $a \in \times_{j \in N} \{0,1\}$, by

$$U(a) = \begin{cases} 2 & \textit{if} \quad \sum_{j \in N} a_j < \infty, \\ 0 & \textit{if} \quad \sum_{j \in N} (1 - a_j) < \infty, \\ \sum_{j \in N} a_j \cdot 2^{-j} & \textit{otherwise.} \end{cases}$$

As before, each agent represents the same individual and therefore they all have the same utility function, implying that property 4.1a is satisfied. Property 4.1b is evident from the payoff functions. If agent *i* switches from action 0 to action 1, then he will be indifferent if $\sum_{j \in \mathbb{N}} a_j$ or $\sum_{j \in \mathbb{N}} (1-a_j)$ are finite and better off by $2^{-i}>0$ otherwise. Consequently, action 1 weakly dominates action 0. As mentioned previously, many harmful addictions are triggered by unhappiness. However, one could also imagine that people try addictive substances because they happen to be in a certain environment, have a friend who suggests a try, etc. In the literature on addiction, it is a well-established fact that peer effects have an enormous impact on, for example, teenagers' smoking behavior (Laux, 2000). In such situations, the person may have a balanced feeling of happiness and uneasiness. The first line in the utility function expresses this feature of the consumption of soft drugs. On a given day, people who rarely use such substances may not even feel any difference between one more or one less consumption and therefore be indifferent between action 1 or 0. The second line illustrates numbness felt by a heavily addicted person. For him, one more or one less intake does not really matter, as he is insensitive to the substance. An alternative way of this stage would be to think of a person who is not experimenting but who is addicted and feels the rewards and the hazardous effects of his consumption at the same time. Such a person would also be indifferent between action 1 and 0. The third line of the utility function above presents the interval in between, that is, when a person is experimenting with addictive substances and every reward of the intake numb out the feelings of uneasiness. A person in this stage would be better off consuming the substance. Thus, consumption is a weakly dominant strategy when taking all the stages into account. There exist an infinite number of equilibria in this game, but we will focus on two of them in order to make our point clear.[24] Conventional game theoretic reasoning would predict that players choose the dominant-strategy equilibrium. Nevertheless, there are infinitely many Nash equilibria with $\sum_{j\in N} a_j < \infty$ that result in the highest payoff. In particular, the equilibrium where everyone chooses the weakly dominated strategy and refrain from consumption is Pareto dominant.

$$U(1,1,...) = 1 < 2 = U(0,0,...)$$

Figure 2 presents this game in its strategic form. For each agent, action 1 weakly dominates action 0. The column to the right, middle and left represent the upper, middle and lower row of the utility function, respectively. The Pareto optimal outcome of this game can result from each agent choosing the weakly dominated strategy while the worst outcome results from choosing the weakly dominant strategy. Again, this is in conflict with the idea of dominance in game theory.

Figure 2. Infinite Coordination Game with Weakly Dominant Strategy

		Finitely many others choose 1	Finitely many others choose 0	Otherwise
Player i	Choose 0	2	0	$0+\sum_{\substack{j\in N \\ j\neq i}} a_j \cdot 2^{-j}$
	Choose 1	2	0	$2^{-i}+\sum_{\substack{j\in N \\ j\neq i}} a_j \cdot 2^{-j}$

Note: The arrows indicate the dominant strategies and encircled are the two Nash equilibria of interest for our analysis.

This game highlights a tension between dominant strategy and Pareto dominant equilibria. Which of these is more likely to attract the players' attention, or using the

[24] Indeed, all $a \in \times_{j\in\mathbb{N}} \{0,1\}$ where either $\sum a_j < \infty$ or $\sum (1- a_j) < \infty$ are pure Nash equilibria. Unilateral deviations cannot change these sums to finite and therefore such deviations cannot increase the payoffs either.

terminology of Schelling (1960), which of these equilibria is focal? In fact, the evidence is rather mixed. It is tempting to believe that players of this game should naturally choose the Pareto dominant outcome. However, experiments testing whether a uniquely Pareto dominant equilibrium provides a sufficient focal point to coordinate behavior in a set of multiple equilibria, suggests that coordination on the payoff dominant equilibrium typically fails in games with a large number of players (Bohnet and Cooter, 2001). Therefore, in accordance with Harsanyi and Selten (1988) and Schelling (1960), there is reason to believe that players in this game will end up in the worst possible outcome of the game by simply playing their weakly dominant strategy.

Moreover, this game shows that a temporary effect, as peer pressure, can permanently "hook" up a rational person to addictive goods. This feature is not only interesting from a welfare perspective but also merits attention when policies are designed to regulate some drugs, for example.

5. Harmful or Beneficial Addiction?

The two preceding games have illustrated harmful addictions. In addition to a harmful addiction, we include a beneficial addiction to our game in this section and show the strategic similarities but welfare differences between these two kinds of addictions.

5.1 Game 3

According to Voorneveld (2007), there are pairs of games[25] , differing only in payoff functions, where

(a) within each game, all players have the same payoff function,

(b) in terms of payoffs, the consequences of unilateral deviations are identical in both games, meaning that they are vNM-equivalent,

(c) nevertheless, these two games have different payoff dominant equilibria.

[25] In fact, these are potential games and the interested reader is recommended to consult Monderer and Shapley (1996) and Voorneveld (2007) for further reading.

If these two games are finite, they cannot have different payoff dominant equilibria. To see this, assume that properties 5.1a and 5.1b hold and that the two games have $n \in \mathbb{N}$ players and payoff functions denoted U and V, respectively. If there are two action profiles $a = (a_1, \dots, a_n)$ and $b = (b_1, \dots, b_n)$, then $U(a) - V(a) = U(b) - V(b)$ must be true. Since the consequences in terms of payoffs must be identical in both games, we can let the first player in a deviate to b_1 and show that

$$U(a) - U(b_1, a_2, \dots, a_n) = V(a) - V(b_1, a_2, \dots, a_n)$$

or after rearranging terms,

$$U(a) - V(a) = U(b_1, a_2, \dots, a_n) - V(b_1, a_2, \dots, a_n).$$

By repeating this argument $n\text{-}1$ times, each time with the next player deviating from a to b, we get

$$U(a) - V(a) = U(b_1, b_2, a_3, \dots, a_n) - V(b_1, b_2, a_3, \dots, a_n) = \dots = U(b) - V(b).$$

Since the difference between these two games is a constant, they also need to have same payoff-dominant equilibria.

5.2 Playing the Piano and Smoking Cigarettes

In the example that follows, we illustrate harmful and beneficial addictions and show that properties 5.1a to 5.1c can hold simultaneously.

Example 3. Suppose each player $i \in \mathbb{N}$ has two pure strategies, 0 and 1, and payoff function $U : \times_{j \in N} \{0,1\} \to \mathbb{R}$ for one game and $V : \times_{j \in N} \{0,1\} \to \mathbb{R}$ for the other, defined, for each $a \in \times_{j \in N} \{0,1\}$, by

$$U(a) = \begin{cases} 0.5 & \text{if} \quad \sum_{j \in N} a_j < \infty, \\ \sum_{j \in N} a_j \cdot 2^{-j} & \text{if} \quad \sum_{j \in N} a_j = \infty. \end{cases}$$

$$V(a) = \begin{cases} 0.5 & \text{if} \quad \sum_{j \in N} a_j < \infty, \\ -2 + \sum_{j \in N} a_j \cdot 2^{-j} & \text{if} \quad \sum_{j \in N} a_j = \infty. \end{cases}$$

The utility functions of the two games, lets call them game A and game B, are illustrated by U and V respectively. By Kolmogorov's Zero-One Law, in every (pure or mixed) strategy profile, the number of agents consuming the addictive substance is either finite with probability one or infinite with probability one. As in the previous section, we consider a person who starts consuming a certain good haphazardly and have counterbalancing feelings of happiness and detest. Such a person will be indifferent between consuming and rejecting the potentially addictive good. However, if this person gets used to the good and even becomes addicted, he will be willing to consume the good every time he gets the chance. Obviously, consumption is his weakly dominant strategy. The equilibrium points, which are infinitely many, are identical in both games but the Pareto optimal equilibria changes radically between the two games.

Consider two actions, playing the piano and smoking cigarettes. The first few times a person plays the piano, he might enjoy playing but have counterbalancing feelings of frustration or pain.[26] This person will either stop playing after a certain number of times or continue playing and become a pianist, in which case he will have an incentive to play more and more. Similarly, a teenager trying cigarettes for the first few times might feel happy (perhaps due to peer conformity) and uneasy at the same time. Such a teenager will either reject the next cigarette he is being offered or continue accepting and become addicted to smoking, in which case he will desire a new cigarette at every occasion. The similarities between these two actions are the consequences of unilateral deviations, that is, a person who is addicted to playing the piano might feel the same loss of utility when refrained from play at one occasion as is a cigarette addict when denied a cigarette. In other words, the craving to play the piano might be as strong as the desire to smoke a cigarette. This is stressed in property 5.1b above. Property 5.1c asserts that in the piano case, playing at every time is the payoff dominant equilibrium, while not smoking a single cigarette is the payoff dominant equilibrium in the cigarette case. Formally, the dominant strategy equilibrium maximizes the payoff function U in the first game, but not the payoff function V in the second game. Thus, the payoff dominant equilibrium changes despite identical consequences of unilateral deviations. Leonard (1989) notes that playing the piano is a beneficial addiction and a self-educating action, which is illustrated in game A. The smoking case exemplifies game B and formalizes a harmful addiction. The strategic form of game A and B are demonstrated in *Figure 3* and *Figure 4*, respectively.

[26] Personally, I remember how my fingers ached after every piano lesson I took at the age of eight.

Figure 3. Beneficial Addiction

		Finitely many others choose 1	Infinitely many others choose 1
Player *i*	Choose 0	0.5	$0+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$
	Choose 1	0.5	$2^{-i}+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$

Note: Encircled are the two Nash equilibria of interest for our analysis. The thicker circle illustrates the payoff dominant equilibria.

Figure 4. Harmful Addiction

		Finitely many others choose 1	Infinitely many others choose 1
Player *i*	Choose 0	0.5	$0-2+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$
	Choose 1	0.5	$2^{-i}-2+\sum_{\substack{j\in N\\ j\neq i}} a_j \cdot 2^{-j}$

Note: Encircled are the two Nash equilibria of interest for our analysis. The thicker circle illustrates the payoff dominant equilibria.

The ambiguity of a focal point when a game possesses a dominant strategy equilibrium which does not coincide with the Pareto dominant one, as mentioned in the previous section, is present in the harmful addiction in game B. Game A, on the other hand, where the dominant strategy equilibrium is also the payoff dominant, has a straightforward focal point which most researchers agree on.

Although the examples used here appear to be rather simple and evident, the intuition behind is not from a standard game theoretic approach. In concordance with property 5.1b, the consequences of using, rather than abstaining from an addictive good, regardless of whether it is a cultural good (as playing the piano) or a cigarette, may well be same. However, the welfare consequences may differ considerably.

6. The Impossibility of Rational Choice

Nash equilibrium is the cornerstone of non-cooperative game theory and therefore a necessary condition for stable behavior among rational agents. The three games presented so far possess at least one Nash equilibrium. We now proceed to the fourth and final game and show that, in addition to the other phenomena, an infinite game does not necessarily possess a Nash equilibrium, not even in mixed strategies. For a person who has to decide on whether to consume addictive substances, this phenomenon imposes a problem: it is impossible for him to make a rational decision.

6.1 Game 4

Peleg (1969) establishes the existence of a mixed strategy Nash equilibria in games with an infinite player set under a continuity condition on the payoff functions. Voorneveld (2007), on the other hand, has shown that using tail events, the existence of equilibrium is no longer evident. In fact, there are games where

(a) all players have the same payoff function,

(b) each player has two pure strategies,

(c) yet there is no Nash equilibrium in either pure or mixed strategies.

Nash (1951) established the foundation for equilibrium existence in finite non-cooperative games. He has shown that every game consisting of a finite set of players, with each player having a finite number of pure strategies, will possess at least one equilibrium in pure and/or mixed strategies.[27] Thus, according to Nash (1951), if properties 6.1a and 6.1b hold and the number of players is finite, 6.1c cannot.

[27] See Nash (1951) for a detailed presentation.

6.2 Cyclical Consumption

In what follows, we exemplify the possibility of the properties 6.1a to 6.1c holding simultaneously by considering a person who wants to consume an addictive substance but not get addicted to it.

Example 4. Imagine each player $i \in N$ has two pure strategies, 0 and 1, and payoff function $U : \times_{j \in N} \{0,1\} \to \mathbb{R}$ defined, for each $a \in \times_{j \in N} \{0,1\}$, by

$$U(a) = \begin{cases} \sum_{j \in N} a_j \cdot 2^{-j} & \text{if} \quad \sum_{j \in N} a_j < \infty, \\ -\sum_{j \in N} a_j \cdot 2^{-j} & \text{if} \quad \sum_{j \in N} a_j = \infty. \end{cases}$$

As in the previous chapter, Kolmogorov's Zero-One Law suggests that the sum of all players choosing strategy 1 will either surely converge to a finite number or diverge to an infinite number. For a single decision-maker, the former implies that he consumes the addictive substance a finite number of times and then quits, while the latter implies that he consumes the substance at infinitely many times. In the first tail event, at every decision he will have an incentive to consume the addictive substance one more time. The motivation for this is similar to the one presented in the first game, namely that certain drugs, for example, give a temporary positive effect which offset feelings of isolation and inadequacy (Shedler and Block, 1990). If this person continues his consumption, he may well end up consuming the addictive substance at all times and become fully addicted, which implies that the second tail event has occurred. In this situation, the person prefers rejecting the substance. Carbone et al. (2005) note that the act of quitting smoking, for example, serves as an investment in health and therefore gives individuals health benefits. This occurs when individuals assume that the mortality risks of their addiction are highly reversible.

Neither in pure nor in mixed strategies are there any Nash equilibria in this game. In order to see this, assume there exists an equilibrium. Consider four cases:

1. Firstly, if $\sum_{j \in N} a_j$ is finite and the equilibrium is in pure strategies, there are players choosing strategy 0 and rejecting an intake. However, these would rather choose 1 and consume one more unit. Thus, this case cannot be an equilibrium.

2. Secondly, if $\sum_{j \in N} a_j$ is infinite and the equilibrium is in pure strategies, there are players consuming the substance but who would be better off rejecting it. Therefore, this case cannot be a Nash equilibrium either.
3. Thirdly, if $\sum_{j \in N} a_j$ is finite and the equilibrium is not in pure strategies, there are players choosing action 0 with positive probability. However, they would be better off deviating and consuming the substance, i.e. choosing action 1 with probability one. Hence, this case cannot be an equilibrium.
4. Finally, if $\sum_{j \in N} a_j$ is infinite and the equilibrium is not in pure strategies, there are players choosing strategy 1 with positive probability. Yet, they would be better off deviating and not consuming the substance, i.e. choosing action 0 with probability one. Thus, this cannot be an equilibrium.

Figure 5 illustrates this game in its strategic form.

Figure 5. Lack of Nash Equilibrium

		Finitely many others choose 1	Infinitely many others choose 1
Player i	Choose 0	$0 + \sum_{\substack{j \in N \\ j \neq i}} a_j \cdot 2^{-j}$	$0 - \sum_{\substack{j \in N \\ j \neq i}} a_j \cdot 2^{-j}$
	Choose 1	$2^{-i} + \sum_{\substack{j \in N \\ j \neq i}} a_j \cdot 2^{-j}$	$-2^{-i} - \sum_{\substack{j \in N \\ j \neq i}} a_j \cdot 2^{-j}$

This model illustrates a common result from empirical studies, namely the existence of binges and cyclical consumption patterns. Examples include smoking, quitting, and starting again, or heavy eating followed by strict dieting. Dockner and Feichtinger (2001) suggest that consumption cycles require two counterbalancing effects: an addictive and a satiating one. The first line of the utility function could be interpreted as the addictive effect, indicating incentives to consume more. Conversely, the second line formalizes the satiation effect, as the decision-maker is better off rejecting further consumption. These counterbalancing effects, for example expressed in terms of desire to eat and a dislike for weight, may result in cycles of eating and dieting throughout a person's life.

The fact that there is no equilibrium implies a problem, regardless of whether the decision makers are agents of a single individual or people of a society. In economics, equilibrium often serves as a rest point, a state that individuals should aim at. In the previous games, such states were present, although they may not have been optimal. Here, such a state does not exist at all. In the absence of equilibria, players may be at a loss to find a prudent course of action.

7. Analysis

The results from the previous sections are rather puzzling from a strategic point of view and show that a standard game theoretic reasoning may lead to undesirable outcomes. In other words, when actions are optimized one at the time, people may find themselves in situations that they regret. This is important from a welfare aspect and persuades me to wonder if there are any ways to avoid these results. According to Schlicht (1998), although simple rules are difficult to design rigorously, they play a major role in our perception of the world and our choices. In this section, I will propose some rules that may guide a person in its decision-making and thereby help to keep away from unintended outcomes.[28]

7.1 Self-Imposed Rules to Limit the Number of Available Strategies

As explained earlier, the results from the infinite games are not possible in finite games. Since all games consider situations where a certain action can be chosen infinitely often, a starting point for an analysis is to imagine how the payoffs changes if the available strategies were limited to a finite number. In other words, we want to keep an infinite number of agents that make independent choices, but limit the occurrence of the strategies leading to the unwanted outcomes.

One way of doing this is to impose a *quantity rule*. For example, a person who will need to decide on whether to smoke could, before lighting the very first cigarette,

[28] These rules are also mentioned in Schelling (1985).

promise himself to only smoke one pack and thereafter never smoke again. This would result in him choosing action 1 20 times and thereafter always choosing action 0.[29] Similar rules can be constructed for a bottle of wine, a chocolate bar or any other consumption or action that one is likely to repeat excessively often if not controlled. Comparable are also rules as “I will buy alcohol for SEK 500 and not more” or for the workaholic “I will work no more than 40 hours per week”. Note, however, that a rule saying “I will only smoke on Saturdays” has the same effect as not having a rule at all.

Given the difficulty of choosing the quantity limit and abiding by it, it may be more convincing to impose *qualitative rules* that forbid the action itself. Although such a rule would not be realistic for a potential workaholic or heavy eater, it would be suitable for a smoker or drinker for instance.

Actions like smoking and drinking are sometimes related to other actions. Examples include those who smoke only when having a coffee or drink only in a bar. A *precautionary rule* that limits the person’s coffee drinking or visits to bars would indirectly also help the person to refrain from consuming the potentially addictive good.

A fourth type of rule would simply be to make it impossible to choose a certain action. A *disabling rule* implies, for example, that a potential pianist never buys a piano or if he has one, he throws it away.

All these very simple rules, if obeyed at each decision point, limit the available strategies and eliminate the possibility of repeating action 1 infinitely often, that is, becoming addicted. Thus, the contradicting incentives between a purely game theoretic reasoning and that of a rational player would be avoided and so would the welfare inferior outcomes.

The question that has to be addressed at this point is whether it is likely to expect a person to obey by any of these rules. Indeed, given the way the games are defined, where each agent has an effect on payoffs but not on determining whether an action is chosen finitely or infinitely often, there are no incentives for the individual agent to obey by any of the rules mentioned above. Playing against a dominant strategy, which would be the case if these rules were followed in the first three games, cannot really be justified. In the case of the fourth game, it might be somewhat easier as there exists no dominant

[29] Assuming that a pack contains 20 cigarettes.

strategy. However, when considering the lifetime utility within a Paretian framework, it is more plausible to expect decision-makers to abide by these rules.

7.2 An Outsider Limits the Number of Available Strategies

Given the difficulty in enforcing self-devised rules, one solution could be to give others the authority to impose rules. Certainly, the outsider must have a legitimate power to impose enforceable rules, otherwise there would be no incentive to abide by them.[30]

An outsider could limit the number of strategies by possessing *control over the access* to the addictive good. For example, by letting your wife be the only one serving your drinks or meals, you would no longer be able to drink or eat as much as you desire. As Becker and Murphy (1988) mention, some addictions end with cold turkey, meaning suddenly. The models presented in this thesis suggest the same and, given the difficulty in ending an addiction alone and gradually, an abrupt cessation might be more realistic with the help of someone else.

Obviously, the outsider could also be a government who intervenes in areas where individuals risk repeating a certain action infinitely often.

In the context of time-inconsistent preferences, simple rules are suggested, among others, by Schelling (1985) and Akerlof (1991). Here, I have stressed the importance of adhering to rules, or if difficult to abide by them, authorizing an outsider to govern a person's actions, even in the case of time-consistent preferences.

9. Conclusion

This thesis modeled a single decision-maker as represented by an infinite number of agents, each making one independent choice. The choices concerned actions that a person is likely to repeat, for example drinking alcohol, smoking a cigarette, consuming drugs or working one more hour. A person who repeats such actions infinitely often was defined as addicted. When assuming that one more or one less unit of consumption does not determine whether a person is addicted or not, the decision problem of such a person becomes rather interesting.

[30] With outsider I mean someone who is exogenous to the model.

Four phenomena have been presented in order to illustrate the dilemma that a person might face when making decisions on whether to consume a potentially addictive good. These paradoxes highlight the contradictory incentives when a decision-maker intends to optimize a certain action (the standard game theoretic approach) or maximize a lifetime utility. Although most people would agree that a person should be more interested in the latter, the illustrations have demonstrated the difficulty in keeping such a focus when the incentives governing the single actions are conflicting.

The analysis has emphasized the crucial role that some very simple rules may play if a person wants, despite the existence of contradicting incentives, to maximize the lifetime utility. Given the difficulty in abiding by self-imposed rules, an independent exogenous actor is suggested to be authorized for intervening and enforcing the rules.

It is worth stressing that, although I have, throughout this thesis, assumed that individuals are rational and have time-consistent preferences, my intention was not to dismiss the role of time-inconsistent preferences in understanding human behavior. Rather, I acknowledge comparable preferences reversals but attempted to show that they may exist even in the standard framework of rational individuals.

As I mentioned in the introduction, there are, so far, three different ways to use infinite player sets. I have kept my analysis on a micro level and focused on a single decision-maker. However, it would also be interesting to apply this framework on a macro level and analyze, for example, political decisions, saving patterns, investment decisions, decisions affecting the environment and fashion trends (especially in the case of the last game, where no Nash equilibrium exists). Such analyses would improve our understanding of the motivations underlying many decisions taken in our society. Of particular importance are such studies when there are diverging incentives between individual actions and the totality of actions.

Finally, due to the nature of the examples used in this thesis, I have not had the means to test the games. I would, however, welcome experiments testing these games, especially with regard to the selected equilibrium points and focal points (when existing). Further research could also be devoted to analyzing the validity of the rules and interventions presented here and of particular benefit for our daily lives would be studies rigorously investigating the appropriateness of different rules in specific situations.

References

Akerlof, G. A. (1991), "Procrastination and Obedience". *American Economic Review* **81** (2), 1-19.

Alcoholics Anonymous World Services, 1975. A Brief Guide to Alcoholics Anonymous. New York.

Artzenius, F., Elga, A. and Hawthorne, J. (2004), "Bayesianism, Infintie Decisions, and Binding". *Mind* **113** (450), 251-83.

Asheim, G. B. and Tungodden, B. (2004), "Resolving Distributional Conflicts Between Generations". *Economic Theory* **24** (1), 221-30.

Aumann, R. J. (1964), "Markets with a Continuum of Traders". *Econometrica* **32** (1-2), 39-50.

Bardsley, P. and Olekalns, N. (1999), Cigarette and Tobacco Consumption: Have Anti-Smoking Policies Made a Difference?". *The Economic Record* **75** (230), 225-40.

Basu, K. (1994), "Group Rationality, Utilitarianism, and Escher's Waterfall". *Games and Economic Behavior* **7** (1), 1-9.

Basu, K. (2000), *Prelude to Political Economy*. Oxford: Oxford University Press.

Basu, K. (2006), "Coercion, Contract and the Limits of the Market". *Social Choice and Welfare*, forthcoming.

Basu, K. and Mitra, T. (2007), "Possibility Theorems for Equitably Aggregating Infinite Utility Systems". In Roemer, J. E. and Suzumura, K. (eds), *Intergenerational Equity and Sustainability*, Palgrave, forthcoming.

Becker, G. S. (1996), *Accounting for Tastes*. Cambridge MA: Harvard University Press.

Becker, G. S., Grossman, M., and Murphy, K. M. (1991), "Rational Addiction and the Effect of Price on Consumption". *American Economic Review* **81** (2), 237-41.

Becker, G. S., Grossman, M., and Murphy, K. M. (1994), "An Empirical Analysis of Cigarette Addiction". *American Economic Review* **84** (3), 396-418.

Becker, G. S. and Murphy, K. M. (1988), "A Theory of Rational Addiction". *Journal of Political Economy* **96** (4), 675-99.

Bohnet, I. and Cooter, R. (2001), "Expressive Law: Framing or Equilibrium Selection?". Mimeo: University of California, Berkeley.

Bool, F. H. (1992), *M. C. Escher: His Life and Complete Graphic Work*. New York: Harry N. Abrams.

Bretteville-Jensen, A. L. (1999), "Addiction and Discounting". *Journal of Health Economics* **18** (4), 393-407.

Brown, R. (1986), *Social Psychology: The Second Edition*. New York: Macmillian.

Camerer, C. F. (2003), *Behavioral Game Theory: Experiments in Strategic Interaction*. Princeton: Princeton University Press.

Carbone, J. C., Kvarnedokk, S., and Røgeberg, O. J. (2005), "Smoking, Health, Risk, and Perception". *Journal of Health Economics* **24** (4), 631-53.

Chaloupka, F. J. (1990), "Men, Women, and Addiction: The Case of Cigarette Smoking". Working Paper No. 3267, National Bureau of Economic Research, Cambridge MA.

Chaloupka, F. J. (1991), "Rational Addiction Behavior and Cigarette Smoking". *Journal of Political Economy* **99** (4), 722-42.

Dockner, E. J. and Feichtinger, G. (1993), "Cyclical Consumption Patterns and Rational Addiction". *American Economic Review* **83** (1), 256-63.

Grossmann, M. and Chaloupka, F. J. (1998), "The Demand for Cocaine by Young Adults: a Rational Addiction Approach". *Journal of Health Economics* **17** (4), 427-74.

Gruber, J. and Köszegi, B. (2001), "Is Addiction Rational? Theory and Evidence". *Quarterly Journal of Economics* **116** (4), 1261-1303.

Harsanyi, J. and Selten, R. (1988), *A General Theory of Equilibrium Selection in Games*. Cambridge: MIT Press.

Keeler, T. E., Hu, T., Barnett, P. G., and Manning, W. G. (1993), "Taxation, Regulation, and Addiction: a Demand Function for Cigarettes Based on Time-Series Evidence". *Journal of Health Economics* **12** (1), 1-18.

Laux, F. L. (2000), "Addiction as a Market Failure: Using Rational Addiction Results to Justify Tobacco Regulation". *Journal of Health Economics* **19** (4), 421-37.

Leonard, D. (1989), "Market Bahavior of Rational Addicts". *Journal of Economic Psychology* **10** (1), 117-44.

Milchtaich, I. (2004), "Random-Player Games". *Games and Economic Behavior* **47** (2), 353-88.

Morris, S. and Ui, T. (2004), "Best Response Equivalence". *Games and Economic Behavior* **49** (2), 260-87.

Monderer, D. and Shapley, L.S. (1996), "Potential Games". *Games and Economic Behavior* **14** (1), 124-43.

Nash, J. (1951), "Non-Cooperative Games". *Annals of Mathematics* **54** (2), 286-95.

Orphanides, A. and Zervos, D. (1995), "Rational Addiction with Learning and Regret". *Journal of Political Economy* **103** (4), 739-58.

Peleg, B. (1969), "Equilibrium Points for Games with Infinitely Many Players". *Journal of the London Mathematical Society* **44** (1), 292-94.

Peele, S. (1985), *The Meaning of Addiction: Compulsive Experience and Its Interpretation*. Lexington MA: Lexington Books.

Perkurinen, M. (1992), *Economic Aspects of Smoking: Is there a Case for Government Intervention in Finland?* Finland: National Agency for Welfare and Helath.

Ramstedt, M. (2001), "Per Capita Alcohol Consumption and Liver Cirrhosis Mortality in 14 European Countries". *Addiction* **96** (1), 19-33.

Rasmusen, E. (2007), *Games and Information, an Introduction to Game Theory*. Oxford: Blackwell Publishing.

Robins, L. N., Helzer, J., Hesselbrook, M., and Wish, E. (1980), "Vietnam Veterans Three Years After Vietnam: How Our Study Changed Our View of Heroin". In Brill, L. and Winick, C. (eds), *The Yearbook of Substance Use and Abuse*. New York: Human Sciences.

Schelling, T. C. (1960), *The Strategy of Conflict*. Oxford: Oxford University Press.

Schelling, T. C. (1984), *Choice and Consequence*. Cambridge MA: Harvard University Press.

Schelling, T. C. (1985), "Enforcing Rules on Oneself". *Journal of Law, Economics, and Organization* **1** (2), 357-74.

Schlicht, E. (1998), *On Custom in the Economy*. Oxford: Clarendon Press.

Shedler, J. and Block, J. (1990), "Adolescent Drug Use and Psychological Health". *American Psychologist* **45** (5), 612-30.

Stigler, G. J. and Becker, G. S. (1977), "De Gustibus non est Disputandum". *American Economic Review* **67** (2), 76-90.

Tomer, J. F. (2001), "Addictions are Not Rational : A Socio-Economic Model of Addictive Behavior". *Journal of Socio-Economics* **30** (3), 243-61.

Van Damme, E. (1996), "Equilibrium Selection in Team Games". In Albers, W., Strobel, M., and Selten, R. (eds), *Understanding Strategic Interaction: Essays in Honor of Reinhard Selten*. New York: Springer.

Voorneveld, M. (2007), "The possibility of impossible stairways and greener grass". SSE/EFI Working Paper Series in Economics and Finance No. 673. Stockholm School of Economics, Stockholm.

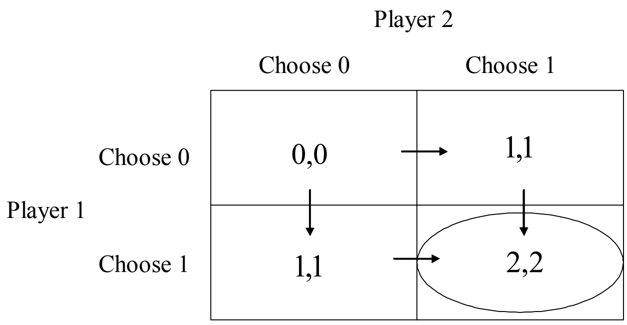
Williams, D. (1991), *Probability with Martingales*. Cambridge, UK: Cambridge University Press.

Appendices

Appendix 1. A Finite Coordination Game with a Strictly Dominant Strategy

Figure 6 illustrates a finite coordination game with two players. For each player, action 1 strictly dominates action 0. In the unique Nash equilibrium (encircled), each player chooses the dominant strategy and the resulting outcome is Pareto optimal.

Figure 6. A Finite Coordination Game with a Strictly Dominant Strategy



Appendix 2. A Finite Coordination Game with a Weakly Dominant Strategy

In the finite coordination game exemplified in *Figure 7,* both players are indifferent between strategy 0 and 1 when the opponent is choosing 0, and better off choosing 1 when the opponent is choosing 1. Thus, action 1 is the weakly dominant strategy. The two Nash equilibria of the game are encircled, the thicker one indicating the Pareto optimal equilibrium.

Figure 7. A Finite Coordination Game with a Weakly Dominant Strategy