A SYSTEM DYNAMICS APPROACH TO THE ENTRY DETTERENCE GAME

Uncovering the dynamic mechanism of the iterated entry deterrence game through a system dynamics model

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Abstract

The research objective is to gain more insight into the dynamics of the iterated entry deterrence game through a system dynamics approach. While the entry deterrence game has been analyzed many times over, a system dynamics approach can generate new insights. Especially since letting go of assumptions that constrain game theory solutions can lead to very different outcomes than those predicted by system dynamics models.

The system dynamics model of the entry showed that the entry deterrence game could not be solved through Bayesian updating and that players instead base their decision on the history of the game. Each decision that the entrant and monopolist make are stored in the history of the game. Based on this history the players determine the probability of the other players' action and their related expected payoffs. Moreover, analysis of the game showed that the amount of risk that the entrant is willing to take to enter the market is a crucial factor. If the entrant is not willing to take any risk, then the entrant will not enter the market if the probability that the monopolist will fight is sufficiently high. Besides a stable amount of risk the model also explored an amount of risk that developed over time. There were three forms of risk tested: declining growth, linear, and increasing growth. Each of the tested models had the same value in the 100^{th} round of the game. Analysis showed that the declining growth model was most successful. Although it was fought more often the entrant enters consistently relatively early on in the game and can profit from this on the long term, because the sooner the entrants enter consistently the sooner the weak monopolist concedes.

At the end of the thesis several recommendations for further research are provided. In general, this thesis confirms the value of modelling games. In relation to the model, there are some elements of the model that needs to be examined more closely such as the risk that the entrant is willing to take.

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1. Introduction

1.1. Background

In the business market a company's profit almost never solely depends on their own behavior, but it is also influenced by the behavior and decisions of other players in the market. The decisions and actions that others in the market take can have a positive or negative impact on another company its profit. Within such a market, a game between two or more entities is, therefore, easily formed (Ahmed & Hegazi, 2006). A possible game that can exist within a market is the entry deterrence game. In the entry deterrence game, there are two players: a monopolist and a firm that is a potential entrant into the monopolist's market. The entrant is likely to enter the market if it can achieve positive profits. If the entrant enters the market then this has negative consequences for the monopolist; the monopolist will no longer be in a monopoly position and consequently its profits will decrease. However, the monopolist can choose to fight the entry with an aggressive market action, but this will cost the monopolist as well. When the entrant enters, the costs of fighting are higher than doing nothing for the monopolist (Carmichael, 2005). The structure of the game is as follows:

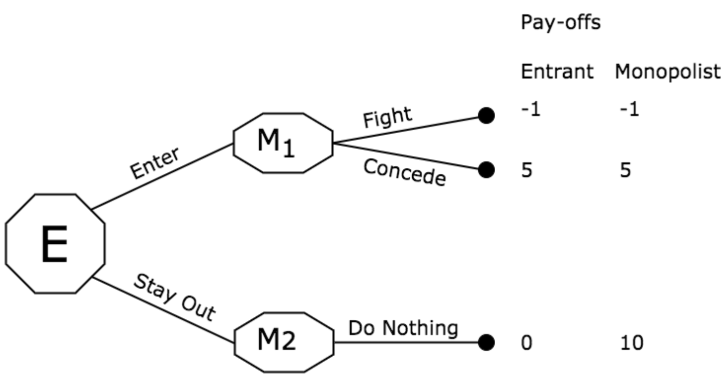


Figure 1. The structure of the entry deterrence game

If the game is only played once, then it makes sense for the entrant to enter the market and for the monopolist to concede. Even in repeated games, where the same players interact more than once, the outcome will not change if the game is played a finite number of times. The subgame perfect equilibrium of the game is entry followed by concede in every round of the game and can be found through backward induction. In this case, the last round of the game first is analyzed and then backward induction is used to work back to the first round. The logic of backward induction shows us that in each round the entrant enters and the monopolist will concede since they have no incentive to fight off the entrant. Intuitively, this outcome feels wrong. It seems more logical that the monopolist will fight off entry to deter entry in a later stage. This is known as the paradox of backward induction, and is related to the entry deterrence game as the chain store paradox (Selten, 1978). To resolve the paradox of backward induction it is necessary to bring some uncertainty in the game. The uncertainty can be about when the game ends, the state of minds of one of the players or the pay-offs of the other player (Kreps et al., 1982).

By building a system dynamics model of the entry deterrence game new insights can be discovered by comparing simulation runs of the system dynamics model with game theory solutions. Furthermore, the system dynamics model can be used to critique the game theory approach if differences emerge (De Gooyert, 2016). System dynamics is a methodological approach for modelling complex systems (Forrester, 1958). Most organizational problems are, due to their nature, suited for a system dynamics approach. They often contain actors that interact with one another. Their actions cause feedback and often generate nonlinear affects through time. These characteristics lead to dynamic complexities that can be studied through a system dynamics model (Sterman, 2000). The entry deterrence game has a dynamic nature and thus is suited for a system dynamics approach. Kim & Kim (1997) showed the value of constructing a system dynamics model for a mixed-strategy game. In their work, they analyzed a game between the police and drivers. In the game drivers had to choose between violating the law or not and Kim & Kim tested the effect of changing the size of the penalty. Their analyses showed that game players should not depend on the equilibrium for choosing their actions, because it takes a very long time for the equilibrium to appear. Furthermore, it showed that an increase in penalty can help to prevent drivers from violating the law. The latter was contradictory to the game-theoretic solution. Their work only focused on the game between police and drivers and is therefore cannot be generalized to other games. Consequently, there is still added value in modelling other games to see if there are differences between the game theory solution and the system dynamics outcome and how these differences can be explained. In conclusion, modelling can help to generate more insight in the entry deterrence game that cannot be gained from a game theory perspective.

1.2. Problem Definition

This research will mainly focus on the dynamics in the entry deterrence game and will have a strong focus on the solution to the entry deterrence game that was proposed by Kreps and Wilson (1982). In their solution of the game the effect of reputation is taken into account. The aim of this research is to gain more insight into the dynamics of the entry deterrence game through a system dynamics approach.

This leads to the following central research question:

What are the dynamic mechanisms in the iterated entry deterrence game?

The main research question can be divided into several subquestions:

What is game theory?

What is the entry deterrence game?

What is the game theoretic solution to the entry deterrence game?

What is system dynamics?

How can the dynamics of the game be modelled?

1.3. Scientific and Social Relevance

The scientific contribution of this research is to gain more insight into the entry deterrence game. Since the introduction of the chain store paradox the entry deterrence game has been analyzed many times over. In the past, Kim & Kim (1997) already showed that modelling a game can generate new insights. Therefore, the scientific contribution for this research lies in revealing what can be learned from a system dynamics approach to the entry deterrence game. The focus will be on unravelling differences between the game theory solution and the system dynamic outcome and to explain how these differences come to be.

The practical relevance of this research is that it can shed some light on some real-word situations. In practice, existing firms often deliberately try to deter the entry of other firms (Edwards, 1955). Companies have a number of strategies to deter entry that they can make use of. These strategies include predatory pricing, the building of excess capacity, raising rivals' costs and product proliferation (Waldman & Jensen, 2014). This thesis provides a clear insight into the rationale behind these strategies.

1.4. Set up of the thesis

To answer the central research question in chapter two a theoretical framework will be given. This chapter will provide insight into what game theory and the entry deterrence game entail. Moreover, the focus for the entry deterrence game is given in this chapter.

After the theoretical framework is given, the methodology of the research is explained in chapter three.

In chapter four the system dynamics model of the entry deterrence game is given and discussed. This chapter will focus on how the model has been constructed. Then, in chapter five the system dynamics model is analyzed and the results of the model are given. In chapter six the validity of the model is discussed.

Chapter seven contains the conclusion and discussion. In this chapter, the central research question is answered. Furthermore, the results, contribution to knowledge and practical implications will be discussed. Moreover, the discussion will contain a reflection on the limitations of this research and directions for further research.

2. Theoretical framework

In this chapter, the theoretical framework for this thesis is laid out. The chapter focuses on multiple theories and sets them apart. Furthermore, the chapter explains the entry deterrence game in depth and explains why the thesis focuses solely on this game.

2.1. Game theory

Game theory is a technique that is used to study how interdependent decision makers make choices and can provide insight into many types of decision making (Waldman & Jensen, 2014). Interdependent decision making means that the decision making of players is dependent on expectations about what others are doing since the outcome of their actions also depends on the actions taken by others in the game. A game always includes players, actions, strategies, payoffs, outcomes, equilibria, and information. Actions are all the possible moves that a player can make. Strategies refers to the rules that instruct each player which action to choose at each point in the game. An equilibrium is a strategy combination that consists of the best strategy for each player in the game. Furthermore, the amount of information that a player has available can differ for each game and even during the game. In games with perfect information each player knows every move others are going to make before moving themselves. In games with imperfect information the players do not know the move of other players. In the case of asymmetric information, not all the players have the same information. Lastly, there is the category of imperfect information. In this case, there is uncertainty about where players are in the game or who they are playing (Carmichael, 2005).

Besides information another important distinction to make between games is the distinction between the sort of game. There are three types of games that can be distinguished: games in strategic form, games in extensive form, and games in coalitional form. Games in strategic form are also known as simultaneous-move games and are often represented by matrixes. In games in strategic form players move at the same time, so their moves are not observed by other players. Games in extensive form are also known as sequential or dynamic games and are represented by game trees. In games in extensive form the players take turns and are aware of each other moves (Carmichael, 2005). Representing games in extensive form as matrices would be inaccurate, because it obscures the fact that one players already knows the other player's action before making a move (Waldman & Jensen, 2014). The entry deterrence game is an example of a game in extensive form. The entrant moves first and the monopolist reacts to the action the entrant took. Games in coalitional form are games in which more than two players negotiate and coalitions of two or more players can form (Von Neumann & Morgenstern, 1944). Coalition games are discussed in depth in subchapter 2.3.

Another important aspect of games is repetition. Some games are only played once and are called one-shot games. Games that are played more than once are called repeated, multistage or n-stage games in which $n > 1$. Most games that involve companies are played repeatedly. This makes it possible for a player's current action to affect future outcomes. Additionally, there is a distinction between finite, indefinite and infinite repeated games. If the game is played a finite number of times then the number of times that the game is played is fixed and there is a clear endgame. If there is an endgame backward induction can be used to predict the outcome of the game. If a game is played for an indefinite number of times then players know that the game is finite, but are unaware of when the game will end. In infinite repeated games players believe that there is no endgame (Carmichael, 2005). Most games played by companies are infinite games. For them there is usually no clear endgame and the players are likely to undertake certain actions hoping it will affect the future strategy of their competitors (Waldman & Jensen, 2014).

The solution of a game depends on the sort of game. Games in strategy forms are solved differently than games in extensive form. Games in strategy form can be solved by determining the dominant-strategy equilibrium, iterated-dominance strategy equilibrium, or the Nash equilibrium. In a dominant-strategy equilibrium each player chooses their dominant strategy. A dominant strategy is a strategy that yields a higher payoff than any of the other strategies that are possible, no matter the choice that is made by other players (Baumol & Blinder, 2009). Not all games have a dominant-strategy equilibrium. If a game does not have a dominant-strategy equilibrium it might have an iterated-dominance equilibrium. An iterated-dominance equilibrium occurs when in a two-player game one of the players has a strictly or weakly dominant strategy. A strictly dominant strategy is a strategy that always yields a strictly higher payoff than other strategies as a response to all the strategies of the other player. A weakly dominant strategy is a strategy that yields equal payoffs as other possible responses to some strategies of the other players and higher payoffs than other strategies in response to at least one of the strategies of the other player. Likewise, the other player should have a best response to the strongly or weakly dominant strategy of the player. If these two conditions are satisfied then the game has an iterated-dominance equilibrium (Carmichael, 2005). If a game does not have a dominant-strategy equilibrium or iterated-dominance strategy equilibrium, it might still have a Nash equilibrium. A Nash equilibrium is a combination of strategies in which each player's strategy is the most profitable response to the other player's strategy (Dufwenberg, 2010). The dominant-strategy equilibrium and iterated-dominance strategy equilibrium are best responses and thus a Nash equilibrium. However, not all Nash equilibria are dominant-strategy or iterated-dominance strategy equilibria.

Games in extensive form consist of multiple decision points in the game. This can resolve in players making threats to make certain moves within the game. If these threads are credible then these threats can influence the behavior of other players. Therefore, the concept of Nash equilibrium needs to be redefined in order to apply to games in extensive form. For games in extensive form the subgame perfect Nash equilibrium is more suitable. The subgame perfect equilibrium rules out strategy combinations that involve non-credible threats. A non-credible threat is a threat that is made by a player in the game, but would not be in the best interest of the player to carry out. The player only makes the threat in the hope that it is believed and that it is not necessary to take action (Carmichael, 2005). For games that are played a finite number of times, the Nash equilibria in each stage game leads to a unique subgame perfect equilibria and the subgame perfect equilibria can often be found through backward induction (Fink, Gates & Humes, 1998). For games that are played an infinite number of times the subgame perfect equilibrium cannot be found through backward induction. In this case, the subgame perfect Nash equilibrium equals the strategies that are credible and played by rational players. A strategy is credible if a rational player would stick to that strategy in any subgame of the complete game (Waldman & Jensen, 2014). Looking at the entry deterrence game in which a weak monopolist is facing an entrant the threat to fight off entry is not credible, since a rational player would choose to concede. A rational player would never choose to fight, because this results in negative pay-offs while conceding does not. Therefore, the entry followed by fighting is not a subgame perfect Nash equilibrium, but entry followed by conceding is. However, there are situations in which the threat to fight of the monopolist can become credible. The entry deterrence game is fully discussed below, in paragraph 2.2.

Additionally, a distinction that is made between games is cooperative versus non-cooperative games. In cooperative games players are allowed to communicate with each other and thus can make agreements with each other about which moves to make. These agreements are enforceable. In non-cooperative games, there is no ability to enforce agreements. Therefore, players have no incentive to agree on mutually beneficial outcomes and are more likely to act in their own self-interest (Carmichael, 2005).

2.2. The entry deterrence game

The entry deterrence game is a simple game in extensive form that according to Selten (1978) produces an inconsistency between game theoretical reasoning and likely human behavior. In this game, a monopolist controls the market and an entrant is considering whether to enter the market or to stay out. The situation can be depicted as follows in a game tree:

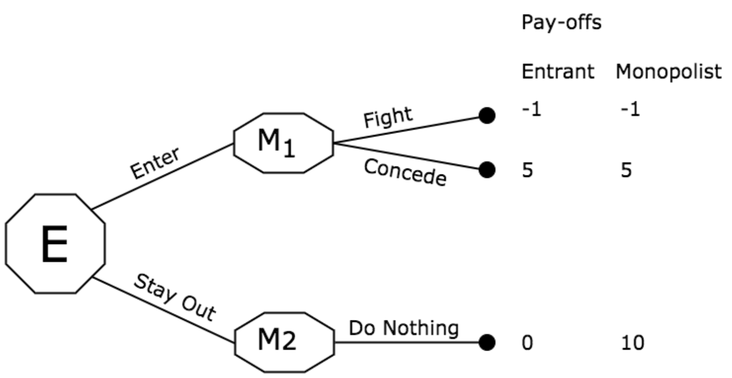


Figure 2. The structure of the entry deterrence game

As stated before, the subgame perfect equilibrium of the game for infinite repeated games is entry followed by concede in every round of the game and can be found through backward induction. The outcome can be found as follows. Imagine that there are ten rounds of the game. With backward induction first the 10th round is analyzed and backward induction is then use to work back from the 10th to the first round. If the entrant now would enter in the 10th round then it is logical for the monopolist to concede. There are no more repetitions of the game, so there is no incentive for the monopolist to do anything else. Conceding will give the monopolist the highest pay-off. The entrant is aware of this situation and will therefore enter in the 10^{th} round. From this it follows that entry followed by conceding is the subgame perfect Nash equilibrium in the 10^{th} round. Knowing what happens in the 10^{th} round the 9^{th} round is analyzed next. If the entrant enters in the 9^{th} round of the game then the monopolist has again no incentive to fight the entry. The monopolist already knows that the entrant will enter in the 10^{th} round of the game, thus fighting in the 9^{th} round of the game will not help to deter entry in a later stage. Each round is analyzed until the first round is reached. In each round the monopolist has no incentive to fight in this case, because it will not deter entry in a later stage in the game. Thus, the unique subgame perfect Nash equilibrium of the game is entry followed by conceding in each round of the game. However, this outcome feels wrong and it seems more logical the monopolist would try to fight entry in the hope of deterring entrance in a later stage of the game. After all, the monopolist can get a higher payoff on the long term if entry is deterred and the market remains a monopoly. This feeling that the outcome that is gained through backward induction is wrong is known as the paradox of backward induction, and related to the entry deterrence game as the chain store paradox (Selten, 1978). To resolve the paradox of backward induction it is necessary to bring some uncertainty in the game. The uncertainty can be about when the game ends, the state of minds of one of the players or the pay-offs of the other player (Kreps et al., 1982). By bringing uncertainty in the game, the players will behave differently and it becomes more logical for the monopolist to fight entry to deter entry in a later stage of the game. Moreover, the paradox of backward induction is heavily debated. It is even argued that game solutions based on backward induction cannot be considered rational. According to this argument backward induction relies on players' belief about what they later will believe and there is a limit to the maximum size of such a chain of beliefs that a player can comprehend. Consequently, a solution based on backward induction is likely to exceed these limits and is therefore not rational (Bacharach, 1992).

This research will mainly focus on the solution to the entry deterrence game that was proposed by Kreps and Wilson (1982). They propose a form of the game in which there is incomplete information about the monopolist pay-offs. The monopolist can either be strong or weak. For the strong monopolist fighting is the best strategy and for the weak monopolist the best strategy is conceding. Nonetheless, the entrant does not know which of the two the monopolist is. The entrant can only estimate with a probability of P that the monopolist is strong. If this probability is high enough, the entrant will be deterred from entering the market. In each round of the game the value for *P* is updated and used by the entrant to make the decision to enter or not. Bayes' rule is applicable to the updating of this probability and, therefore, the updating of the probability during the game is also known as Bayesian updating. Only when the monopolist concedes, the entrant can be sure that they are dealing with a weak monopolist. Thus, even when the monopolist is weak, they can make the threat to fight credible by pretending to be a strong monopolist. The focus is on this solution, because it allows the firm's reputation to be taken into account. This solution is therefore more in line with the behavior that is seen in the real system. In the real system, some companies build up a reputation as being though and willing to gain in price wars in the hope of deterring other rivals to enter in the market (Scherer, 1980; Rosenthal, 1979) Moreover, the assumption that players are uncertain about each other's pay-offs is a very strong assumption for any real-world applications (Kreps & Wilson, 1982). Moreover, the solution lends itself for system dynamics modelling, since there is a clear feedback loop; each decision influences the decision that is made in the next round.

As discussed above, the probability that the entrant attributes to the monopolist being strong is updated according to Bayes' rule. If n = 1 is the last round of the game, n = 2 is the round before that, n =3 the round before that, etc. Then, in line with this rule P_{n-1} should be updated as follows after the nth round of the game:

$$P_{n-1} = \frac{P_n}{P_n + X_n(1 - P_n)}$$

In this equation, X_n stands for the probability that the monopolists will fight in the nth round of the game. If X_n equals zero then P_{n-1} equals one, thus in the case the X_n equals zero the entrant knows that the monopolist is strong if the entry was fought. However, if X_n equals one then the change of fighting is the same for both a strong and weak monopolist, so the entrant learns nothing from an entry followed by fighting. In such a case P_{n-1} equals P_n. From this it follows that in order to remain credible the weak monopolist must randomize between conceding in fighting so that $0 < X_n < 1$. If the monopolist ever chooses to concede then the value of P_{n-1} is updated to zero. Consequently, the entrant will enter in every following round after entry was followed by conceding.

Based on this information the game can be solved. The generalized payoffs of the game can be depicted as follows (Carmichael, 2005):

	Entrant	Weak Monopolist	Strong Monopolist
Entry followed by fight	e - 1	-1	0
Entry followed by concede	e	0	-1
Entrant stays out	0	m	m

m > 1, 0 < e < 1

Table 1. The payoffs in the entry deterrence game.

The strategies of the monopolist are as follows:

Strong monopolist: always fight

Weak monopolist: fight entry with a probability of X_n

The entrant has the following strategy:

If $P_n > P_n^*$ stay out

If $P_n < P_n^*$ enter

If $P_n = P_n^*$ randomize between entering and staying out with a probability of Y_n.

P_n^* stands for the critical value of P_n where the expected payoffs from entering are equal to the expected payoff from staying out for the entrant.

In these strategies n = N, the number of times the game is repeated.

The expected payoffs from entry are the probability that the monopolist is strong multiplied by the payoffs for entry followed by fight, adding the probability that the monopolist is weak multiplied by change that the monopolist will fight and multiplied by the expected payoffs, and adding the probability that the monopolist is weak multiplied by the change that the monopolist will concede times the payoffs for entry followed by conceding. The critical value of P_n can be determined by setting the expected payoffs from entry equal to the expected payoffs from staying out. The expected payoffs from staying out are zero. So, the expected payoffs from entry should be set equal to zero:

$$EPO_{entry} = P_n(e-1) + (1-P_n)(X_n)(e-1) + (1-P_n)(1-X_n)\,e = 0$$

X_n is the probability that the weak monopolist will fight. X_n can be determined as follows:

$$(1 - X_n) = \frac{(1-e)}{1-P_n}$$

$$X_n = \frac{(e-P_n)}{(1-P_n)}$$

Since X_n is known the critical value of P_n can be calculated. P_n* is calculated in three steps. First, P_1* is calculated, this is the critical value of P in the last repetition of the game. In the second step an expression for P_2* is calculated and in the third step the results are generalized.

P_1* In the last repetition X_1 = 0. Therefore, the equation to set the expected pay-offs equal is easier:

$$P_1(e-1) + (1-P_1)e = 0$$

$$P_1 = e$$

So, P_1* is equal to e. Bayes' rule can now be applied to determine P_2*. Based on Bayes' rule the following equation needs to be solved:

$$P_1^* = e = \frac{P_2^*}{P_2^* + (1-P_2^*)X_2}$$

$$P_2^* = e^2$$

Based on these results the generalized results can be stated as follows:

$$P_n^* = e^n$$

Now X_n and P_n* have been defined only Y_n still needs to be formulated. Y_n is the probability that the entrant will stay out in the nth round of the game if in this round P_n = P_n*. This condition can only be satisfied if the weak monopolist is randomizing as well between fighting and conceding. The monopolist is likely to randomize when the expected payoffs from fighting are equal to the expected payoffs from conceding. Setting these two equal for the penultimate repetition of the game, so the round before the last round, yields the following results:

$$EPO_{fight} = EPO_{concede}$$

$$-1 + Y_1\,\mathrm{m} + (1-Y_1)0 = 0$$

$$Y_1 = \frac{1}{m}$$

Generalizing these results yields the following equation:

$$Y_n = \frac{1}{m}$$

Based on the formulations the player's strategies can be redefined as follows for the monopolist:

Strong monopolist: always fight

Weak monopolist: fight entry if $p_n \geq e^{n-1}$ and fight with a probability of X_n if $p_n < e^{n-1}$. Where $X_n = \frac{(e-P_n)}{(1-P_n)}$. Furthermore, the weak monopolist should concede if they conceded before and concede in the last round.

The entrant has the following strategy:

If $P_n > e^n$ stay out

If $P_n < e^n$ enter

If $P_n = P_n^*$ randomize between entering and staying out with a probability of $\frac{1}{m}$.

From these strategies, it follows that entry can be deterred if $P_n > e^n$. From this it follows that entry is likely to be deterred in an earlier round of the game and that as the game goes on and e^n becomes larger entry becomes more likely (Carmichael, 2005). This outcome of the game is more in line with the intuitive prediction that the monopolist will fight entry in the hope of deterring entry in later rounds of the game. This is known as the reputation effect. The monopolist can make use of their reputation to deter entry. However, the outcome of the game tells us that as the game processes the reputation effect is worth less and it becomes harder to deter entry. Based on the above-mentioned formulation the entrant is more likely to repeatedly enter in later stages of the game and it is thus becomes more likely that the weak monopolist will concede at some point in the game. Furthermore, the nature of the entrant is important as well. The entrant can also build up a reputation for always entering (Kreps & Wilson, 1982).

2.3. Cooperative game theory

The entry deterrence game is a non-cooperative game; agreements made between players are not binding. In game theory, there are also cooperative games. In cooperative games agreements can be made that are binding or enforceable. Thus, for games the outcome can be very different if they are played as cooperative or non-cooperative games (Carmichael, 2005). Moreover, cooperative game theory differs from non-cooperative theory in the sense that it focuses more on what groups of players can achieve rather than on what individuals can do (Osborne & Rubinstein, 1994). For these games, when more than two parties negotiate coalitions of two or more parties can form. These games are studied under the name '*n*-person games in characteristic function form' (Von Neumann & Morgenstern, 1944). In these games there is a universe, *U*, of *n* players where n $\geq$ 3. N is the set of players and a coalition, *S*, is any subset of N. A player may gain by forming a coalition. A characteristic function $v: 2^N$ → *Re* assigns a value (real number) to each coalition S $\subseteq$ N. Herby, *Re* is the set of real numbers. For any coalition, of players *V(S)* is the value of the coalition *S*. A coalition game is an ordered pair $< N, v >$ where v is a characteristic function and N a player set (Raiffa, Richardson & Metcalfe, 2002). Not all *n*-person games are cooperative. *n*-person games can be non-cooperative. In these games, it is impossible to form coalitions since agreements are not binding. In everyday strategic situations, this is often the case and sometimes it is even illegal for companies to form binding coalitions (Colman, 1995).

2.3.1. Variable-sum and constant-sum games

In coalition games, there is a distinction between variable-sum and constant-sum games. A constant-sum game is a game in which the sum of all player's payoffs is equal to a constant. If that constant is zero then it is called a zero-sum game. Furthermore, a game in coalition form should always satisfy three axioms. Firstly, $v(\emptyset) = 0$, the value of the empty coalition should be zero. Secondly, $v(S) + v(N - S) = v(N)$ for all coalitions S. Thirdly, $v(S \cup T) \geq v(S) + v(T) for\ S \cap T = \emptyset$. The last axiom is known as super-additivity.

A game is a variable sum game if axiom two is released for the game. So, it only satisfies the first and third axiom. To sum up, a game is a variable-sum game if the value of the empty coalition is zero and the axiom of super-additivity is satisfied (Raiffa, Richardson & Metcalfe, 2002).

2.3.2. Solutions to coalition games

In coalition games the payoff vectors denote the division of the bribe amongst the players as follows:

$x = (x_1, \dots, x_n)$

This denotes the payoff a player gets given the outcome of the game. A payoff vector is called an imputation it if satisfies both individual and collective rationality. There is individual rationality if the payoff for a player is at least as great as its value. Individual rationality is:

$x_i \geq v(\{i\}) for\ every$

collective rationality is depicted as follows:

$\sum_{i \in N} x_i = v(N)$

Since the set of imputations is usually very large it is necessary to look at other solution concepts to predict the outcomes of coalition games. Two well-known solution concepts are the core and the Shapley value. The core is the set of all imputations satisfying group rationality. Group rationality is:

$\sum_{i \epsilon S} x_i \geq v(S) for\ every\ coalition\ S \subseteq N$

Group rationality always implies individual and collective rationality and that no coalition or member in a coalition can improve itself. Therefore, there is no incentive to deviate from the core. So, a core imputation is stable (Raiffa, Richardson & Metcalfe, 2002). However, the core is empty for some games while in other games the core might consist of multiple imputations. The latter results in the core allocation problem. If the core contains more than one imputation then it is unclear what a reasonable player can expect from the game (Peleg & Sudhölter, 2003). However, even if the core consists of multiple imputations it still is a valuable concept, because it gives an overview of the imputations for which no group has a preferable competitive alternative (McCain, 2013).

Unlike the core, the Shapley value consists of a single imputation. This value approach presupposes a sequential form of negotiations and coalition formation. For each player, their added value to a coalition is called their marginal contribution. According to the Shapley solution concept for n-person games in coalition function form, each coalition has a certain probability of occurrence which depends on the ordering of formation. Each player can calculate their expected value of the game by multiplying through their marginal contributions to coalitions with the chance of occurrence of the coalitions. This expected value is called the Shapley value of the player. So, the Shapley value of a player is the weighted average of their marginal contributions to any coalition. The core idea of the Shapley value is the bargaining power of the player. It is an a priori evaluation of the worth of the player for the whole coalition game to be played. The Shapley value is considered a fair solution (Raiffa, Richardson & Metcalfe, 2002).

2.3.3. Offensive and defensive coalitions

When forming coalitions, it is possible that players will form offensive or defensive coalitions. This is the ability of coalitions to commit to offensive or defensive threats against other coalitions. In this case, there might be a potential conflict between the coalition, *S*, and the complementary coalition, *N/S*. Three assumptions are applicable to the ability to commit to an offensive or defensive threat against another coalition. The first assumption entails that players in *S* should guarantee themselves the maximal sum of individual payoffs against the best offensive of *N/S*. This is the minimax representation in coalitional form of the strategic game. This representation thus implicitly assumes that players in *S* should be concerned that the players in *N/S* will attack *S* offensively if they do not include these players in their coalition (Von Neumann & Morgenstern, 1944). The second assumption is that complementary coalitions, *N/S*, would play defensive equilibrium strategies against each other. The underlying assumption here is that *N/S* will play its equilibrium strategy and thus *S* chooses for a defensive strategy by playing its equilibrium strategy as well. The equilibrium strategy of *S* will maximize the individual payoffs for the players in *S* as well as for the players in *N/S* (Schmidt, 2002). The third assumption is the rational threats representation and generalizes Nash's rational threat criterion. Applied to coalition this entails that the equilibrium strategy of *S* (*N/S*) maximizes their sum of individual payoffs minus the individual payoffs in *N/S* (*S*). For each of these assumptions, there are different scenarios of cooperative games applicable (Harsanyi, 1963).

2.4. Market games

A market game is a game explaining price formation through game theory. A market is an exchange economy with money, in which the players have utility functions that are continuous and concave (Shapley & Shubik, 1997). Based on game theory markets can be analyzed to motivate or justify why some markets show certain behavior, such as price-taking behavior. In general, when analyzing this behavior, a research should consist of three steps. First, the market should be described. This includes the describing of players and their preferences. Secondly, based on this information an extensive-form market game should be defined to describe the behavior of the players in the market. This includes determining which information is available to players and what their payoffs are. Thirdly, the game should be thoroughly analyzed. The goal of the latter analysis is to show that under certain conditions the equilibrium outcome of the game is a perfectly competitive equilibrium of the original market (Gale, 2002).

2.5. Market power theory

Market-power theory is concerned with how firms can improve their competitive success by securing stronger positions in their market (Child, Faulkner & Tallman, 2005). Based on the position that companies hold within their market there are generic strategies that are most viable and profitable for them (Porter, 1980). In market power theory, the forming of offensive and defensive coalitions can be important as well. Companies might be able to increase their market power by engaging in a cooperative strategy that offers a mutually advantageous opportunity for both firms (Child, Faulkner & Tallman, 2005). In this case, the forming of offensive coalitions is done to strengthen their competitive advantages and strengthen their position while diminishing other competitor's market share or by raising their product or distribution costs. At the same time, offensive coalitions can have a negative effect. They can reduce the partners' adaptability in the long run (Porter & Fuller, 1986). On the other hand, firms can form defensive coalitions. Defensive coalitions are made to construct entry barriers in the hope of securing their own position in the market, stabilizing the industry, and increasing their own profits. Moreover, a defensive coalition can also be formed by smaller players in the market to be able to compete with dominant players in the market. The nature of a coalition can be two-fold: while for one company the coalition has defensive purposes, for the other the coalition might have offensive purposes. Additionally, the nature of a coalition can shift after it has been formed (Child, Faulkner & Tallman, 2005).

2.6. System dynamics and games

Games are often suited for a system dynamics approach due to their dynamic nature. In most games, the history of the game influences the decisions that are made further on in the game. Games can represent different problems and thus are used in different fields of study, from biology to management, to explain behavior. One of these fields in which games are used to provide insight in decision making is the field of strategic management. Strategic management focuses on the dynamics of the firm's relation with its environment for which actions can be taken to achieve the organization's goals and to increase their performance with the rational use of resources (Ronda-Pupo and Guerras-Martin, 2012). Within strategic management, there are four main research streams to which system dynamics can contribute to research (Gary et al., 2008). One of these streams is game theory models of competitive rivalry which are aimed at providing insight into the consequences of interdependent decision-making amongst firms. System dynamics can help provide insight in these cases, because other solution concepts often rely on assumptions that have been called into question by recent research. Letting go of these assumptions, that constrain for example game theory solutions, can lead to very different outcomes than those predicted by other models (Sterman et al., 2007). Thus, this area of games is highly suited for a system dynamics approach and by modelling these games much insight can be gained.

In general, there are two approaches that can be used to model strategic games. When modelling these games, it is important to preserve the probability of the player's behavior. This can be done by interpreting the probability of the player's behaviors in terms of the history of previous games (Kim & Kim, 1995). The history of a game can be approached in several different ways of which three are the most common. Firstly, history can be told as news, following a chronological order. This kind of history holds little explanatory power. Secondly, history can be told from the point of view of a single actor. This method is often easiest to understand and offers a lot in terms of explanatory powers. Thirdly, history can be told from a global point of view. Although this way can provide insight into large scale patterns, they often do not offer an explanation for these patterns (Axelrod, 1997). Another way to conceptualize the probability of the players' behavior is to extend the model to a population instead of individual players (Kim & Kim, 1997). The approach in which history is told from the point of view of a single actor however fits best with the entry deterrence game since the monopolist and entrant are single actors. Furthermore, this method offers most in terms of explanatory powers in relation to the entry deterrence game. System dynamics as a method is explained more in depth in chapter three.

2.6.1. Choice for entry deterrence game

This chapter discussed non-cooperative games, cooperative-games and market power theory on entrance in markets. While all three are suitable for further system dynamics research, this research focuses on the entry deterrence game. The non-cooperative entry deterrence game has been discussed much in the literature since its introduction in 1978 by Selten. However, there is no system dynamics model of the entry deterrence game despite the possible insights this could bring. Especially since there is a clear underlying feedback mechanism in the game. Each round that is played in the game, influences decisions that are made later in the game. So, in the iterated entry deterrence game the dynamic mechanism of the game consists of the players that make decisions over time which are affected by past decisions. These past decisions are stored in the history of the game and are used in each round to determine the player's decision. Due to this clear feedback loop the game is highly suitable for a system dynamics approach. Consequently, this research focuses on contributing to the discussion about the entry deterrence game by approaching it with a different yet highly suitable method since it can capture the dynamics of the entry deterrence game. The necessity of a system dynamics model of the entry deterrence game lies in the fact that this model is not constrained by the game theoretic assumptions and is therefore likely to lead to different outcomes than those predicted by the game theoretic outcome (Sterman et al., 2007). Assumptions made in game theory are often violated in real world situations. Especially, the cognitive and social psychological assumptions are often critiqued, such as perfectly accurate forecasting (Burns & Roszkowska, 2005; Camerer, Ho & Chong, 2015). For the system dynamics model the probability of the player's behaviors will be modelled in terms of the history of previous games (Kim & Kim, 1995). The system dynamics model especially helps to investigate the difference between the game-theoretic recommendation and the dynamics of social system (Kim & Kim, 1997). This novelty is less applicable for models that focuses on securing market shares. Since research has been conducted in this area (Kortelainen & Karkkainen, 2011). Furthermore, the resources for this research are limited. Due to the limited amount of time that is available to conduct research it is better to focus on a well-defined topic, such as the entry deterrence game. To sum up, this research focuses on the entry deterrence game based on both pragmatic as well as theoretical grounds.

3. Method

This research consists of a quantitative study in which the research question will be answered with the help of simulation techniques. A system dynamics model is constructed with the help of Vensim. Vensim is simulation software and is used for developing and analyzing dynamic models. The version of the software that is used in this research is Vensim PLE, since this version of the software is free for educational use. This chapter provides background information, the choice for simulation and the validity of system dynamic models.

3.1. Background

System dynamics is a method that was developed during the 1950s by Jay Wright Forrester for modelling and simulating complex physical and social systems (Forrester, 1958). The method brought together concepts of different fields such as control engineering and organizational theory (Meadows, 1980). The methods aim is to study managerial and dynamic decisions (Forrester, 1961). System dynamics is a method that combines first-order linear and non-linear difference equations to relate qualitative and quantitative factors within and across time periods (Sterman, 2000). The method provides tools that help to describe the structure and dynamics of complex, non-linear, multi-loop feedback systems (Richardson, 1999a). Since its existence, system dynamics has been successfully applied to numerous fields such as industrial company problems, management, economics, public policy design, and environmental studies. System dynamics is designed to analyze dynamic tendencies of complex systems, especially what kind of behavioral patterns they generate over time. In system dynamics, the underlying assumption is that the causal structure of the system is causing these patterns. The system is a closed boundary that entails all relevant variables (Cosenz & Noto, 2016). The structure is determined by physical or social constraints, goals, rewards and pressures that make an entity in the system behave in a certain way (Meadows, 1980). Applied to organizations, the principle dictates that the process structure determines the system behavior, and the system behavior determines the organization performance (Davidsen, 1991; Richardson & Pugh, 1981). Consequently, organizations employ system dynamics to develop sustainable strategies by gaining insight in the relationship between process and behavior and finding leverage points within the system (Ghaffarzadegan et al., 2011).

3.2. The value of simulation

In the field of system dynamics there is an ongoing discussion about the validity of system dynamic models and the necessity of quantification of qualitative models. Below the difference between qualitative and quantitative modelling is explained and in the next subchapter the validity of system dynamic models is discussed. Although this research builds a quantitative model and not a qualitative one, it is still interesting to briefly describe this discussion, since the discussion also entails the insights that can be gained from the quantification and simulation of models.

In some cases, describing the system itself might already be a useful thing to do and a qualitative model can sometimes already have the desired outcome and lead to a better understanding of the problem at hand. Sometimes a qualitative model might even be better since quantified models have their own shortcomings (Richardson, 1999b). Although quantification always leads to a better insight in a problem it might be fraught if there are many uncertainties within the model. This is especially the case when introducing soft variables within the system which are hard to quantify. The more uncertainty there is within the model the higher the chance that the model output is misleading and any conclusions drawn from it might be illusory (Coyle, 2000). When modelling it is therefore important to determine the value that quantified modeling adds to qualitative analysis and if the value of the variables can really be determined without making nonsense (Axelrod, 1997).

However, others in the literature have argued that quantifying a model always adds value. Quantified models can be simulated. Simulation is the driving of a model of a system with suitable inputs while observing the corresponding outputs (Bratley, Fox, & Schrage, 1987). Even when there are significant uncertainties about the formulation of (soft) variables, simulation can still add value. Simulation models are formally testable which makes it possible to draw behavioral inferences reliably through simulation in a way that is rarely possible with qualitative models. Furthermore, if there are significant uncertainties within the model that make it impossible to draw conclusions from it, then simulation at least gives insight into the information that should be gathered to strengthen the model (Homer & Olivia, 2001).

Simulation can serve diverse purposes including prediction, performance, training, education, proof, and discovery. As a scientific methodology, the value of simulation lies within its usage for prediction, proof and discovery. Simulation research lies somewhere between the two standard methods of doing science; induction and deduction. Simulation research starts, like deduction, with a set of explicit assumptions. However, unlike deduction, it does not prove theorems. The data that is generated through the simulation of a model can be analyzed inductively. The difference between simulation and induction is that the simulated data comes for a rigorously specified set of rules rather than from direct measurements of the real world (Axelrod, 1997)

Consequently, this research will gather data through simulation of a system dynamics model. The data that is generated with this model will be analyzed inductively. For this research, the value in simulation lies within its usage for proof and discovery. By simulating, new insight can be discovered by comparing simulation runs with the game theory solutions. If differences emerge, the model can be used to critique the game theory approach (De Gooyert, 2016).

3.3. Modelling decisions

When modelling decisions, the modeler should first focus on the higher levels of hierarchy and later on the lower levels within the hierarchy. Modelling is always an iterative process, but the modeler should always try to first identify all the feedback loops within the system before focusing on the more detailed level of the substructure (Forrester, 1968b). The structure of models is based on two different kinds of assumptions. There are assumptions about the physical and institutional environment. These assumptions include the model boundary and stock and flow structures that characterize the system. On the other hand, there are assumptions about the decision process of the agents that operate in those structures. These are the decision rules that determine the behavior of the actors within the system. There is a difference between decision rules and decisions. Decision rules are the protocols that specify how decision makers process available information. Decisions are the results of applying these decision rules (Sterman, 2000). It is important to model the decision rule and not only the decision itself (Forrester, 1961). Consequently, the information that is used for the decision-making process and how decisions are based on the available information should be incorporated in the model.

When modelling decision rules there are five fundamental principles that should be adhered. These principles are the Baker criterion, conformation to managerial practice, distinguishing between desired and actual conditions, robustness under extreme conditions, and equilibrium should not be assumed. The first decision rule, the Baker criterion, entails that decision rules should always be based on available information. If something is not known, it cannot be used as information input for the decision rule. This criterion has three implications. Firstly, the future cannot be known by anyone. So, expectations and beliefs about the future should always be based on historical information. Secondly, perceptions might differ from the actual conditions since beliefs might not be updated immediately when new information is received. Thirdly, outcomes of 'what if' situations that have never been experienced cannot be known and when modelled might be wrong. Hence, in general this decision rule states that decisions should be based on information that is currently available to decision makers. The true consequences of decisions that have not been realized yet cannot be known nor is future information available to the decision maker. Consequently, a system dynamics model based on backwards induction would be wrong, since such a model bases the entrant's decision on what they know in the future. The second decision rule states that a model should always confirm to managerial practice. This rule implies that all variables in the model should have a real world equivalent and equations should be dimensionally consistent. The third rule states that desired and actual conditions should be separated from each other in the model. Furthermore, any constraints to the realization of desired outcomes should be present in the model as well. The fourth rule states that decision rules should be robust even under extreme conditions. The rule states that the behavior that is shown by the model should be plausible and operationally meaningful even when the inputs of the model are taken to extreme values. The fifth decision principle states that equilibrium should not be assumed. This principle implies that a modeler should not hold the presumption that an equilibrium will appear. Instead, model analysis should reveal if the behavior generated by the model is stable or unstable (Sterman, 2000). These five formulation fundamentals influence the system dynamics model that is based on the entry deterrence game, since the model needs to be in line with these principles.

3.4. The Validity of SD Models

When modelling a simulation model, it is always important to achieve three goals: validity, suability, and extendibility. Usability refers to the ability of researchers and others to run the program, interpret its output, and understanding how the model works. The goal of extendibility it to allow others to adapt the program for new uses in the future. The goal of validity refers to the program correctly implementing the model. This is the internal validity of the model and is very important. It is critical to know that the model is programmed correctly, because only then it is possible to know if unexpected behavior in the model is caused by mistakes in the model or are surprising consequences of the model (Axelrod, 1997).

When it comes to the validity of models there are two common paradigms. On the one hand, there is the logic empiricist philosophy on model validation and on the other hand there is the relativist philosophy of science. Whereas the logic empiricist philosophy assumes that knowledge is an objective representation of reality, the relativist philosophy of science states that knowledge is relative to a given society, epoch, and scientific world view. Within this view theory justification is a semiformal, relative social process. The relativist philosophy of science is consistent with the system dynamics paradigm that validation is relative (Barlas & Carpenter, 1990). The validity of system dynamic models always depends on the purpose of the model. System dynamic model validity is a relative concept in which the explanatory power of the model and predictive power of the model are both very important (Forrester, 1961). The validity of system dynamic models is strongly tied to the nature and context of the problem, the purpose of the model, the background of the user, the background of the analysist, and other considerations (Barlas & Carpenter, 1990).

Model validation takes place in every stage of the modelling process, but especially after the initial model formulation. The logical sequence in which various validation activities must be carried out is: structural tests, structure-oriented behavior tests, and behavior pattern tests. Structure-oriented behavior tests are of special importance; they can provide information on potential structure flaws. They also combine the strength of structural orientation with the advantage of being quantifiable (Barlas, 1996).

3.4.1. Structural tests

Structural tests assess the validity of the structure of the model by comparing it with the structure of the real system (Barlas, 1996). There are several structural tests: the structure verification tests, the parameter verification tests, the extreme condition tests, the boundary adequacy test, and the dimensional consistency test (Forrester & Senge, 1980). The structure and parameter verification test are empirical tests. They are empirical because they compare the model structure with quantitative or qualitative information gathered from the real system. The other tests are theoretical of nature and compare the structure with generalized knowledge about the system that is known from literature (Barlas, 1996). The structure verification test tests if the model structure is in line with the knowledge about the structure of the real system. The parameter verification test checks whether each parameter matches the elements within the system and if the value of the parameter lies within plausible ranges. The extreme condition test focuses on what happens if extreme values are entered in the model. Extreme values are entered in the model to test if each decision in the model still results in plausible output. Simulation is not required for this test. The boundary adequacy test focuses on the boundaries of the model. It is tested if the model contains all the relevant elements that are needed for the purpose of the model. This test first sees if there are any doubts about what is missing, then identifies structure to be included and tests if the new structure has a strong influence on the model. The dimensional consistency test checks if equations are dimensionally consistent. System dynamic models are made up out of equations and in algebraic equations the units on the left-hand side of the equations should match the units on the right-hand side of the equations (Forrester & Senge, 1980). All these tests will be conducted for this research.

3.4.2. Structure-oriented behavior tests

Structure-oriented behavior tests test the validity of the structure indirectly by reviewing the model-generated behavior patterns (Barlas, 1989a). Structure-oriented behavior tests include symptom generation test, frequency and phase relationship test, multiple mode test, characteristics test, pattern and event prediction test, anomaly test, family member test, surprise behavior test, sensitivity test, and changed behavior prediction test, and policy sensitivity test. The symptom generation test checks if the behavior matches the reference mode. With the frequency and phase relationship test it can be tested whether phase relationships between variables and frequencies for individual variables are similar in the model and the real system. The multiple mode test checks if the model reproduces more than one mode of behavior. The characteristics test analysis if the pattern of behavior of the model matches the real system in general. As a consequence, the shape of the curves, peaks, and unusual events are compared. The pattern and event prediction test focuses on whether the behavior that is predicted by the model is plausible in the real system. The anomaly test checks if the predictions of the model are different from what is expected under certain assumptions. The family member test is used to determine if the model behavior corresponds to expected behavior of corresponding systems. The surprise behavior test is used to check if surprising behavior that occurs in the model also occurs in the real system. The sensitivity test is used to test if the model behaves as expected under different combinations of parameter values. The changed behavior prediction test is a test that can be used if policies have been implemented in the test. The test can then be used to check if the model behaves as expected if past policies are implemented again. Lastly, the policy sensitivity test. This test checks how sensitive the model is to different values in the policy parameters. This is useful when checking the robustness of policies. The less sensitive the results are, the more robust the policy is (Forrester & Senge, 1980). Since there is no reference mode of behavior or policies to implement for this model the symptom generation tests, frequency & phase relationship, multiple mode test, characteristics test, family member test, change behavior prediction test, and policy sensitivity test will not be conducted for this research.

3.4.3. Behavior pattern tests

The last set of tests are behavior pattern test. Only after first assessing the validity of the model structure it is possible to determine the validity of the behavior patterns that the model reproduces. With these tests the focus is on the prediction of patterns and not on events. The focus on the prediction of patterns rather than events comes from the long-term orientation that system dynamics upholds (Barlas, 1996). Even perfect structures might not be able to accurately predict events (Barlas, 1989b; Forrester & Senge, 1980). To determine which test can be used it is important to first determine if the model shows steady-state or transient behavior (Barlas, 1996). In the case of transient behavior graphical measures of typical behavior patterns are compared such as slope and minimum value (Forrester & Senge, 1980; Barlas, 1985; Carson & Flood, 1990). For the testing of steady-state behavior Barlas (1985;

1989b) developed a six-step procedure that includes comparing the averages and variations. Furthermore, it is possible to conduct some statistical test for behavior validation. However, statistical significance testing is not always suitable for testing system dynamic models. Statistical tests for system dynamic models are only useful if they focus on pattern-oriented rather than point-oriented behavior (Barlas, 1996). Most behavior pattern tests cannot be conducted for the model, since there is no observed real world behavior to compare the model to. Therefore, the behavior is only validated through the plausibility and consistency test. The plausibility test focuses on model survival while the consistency test focuses on stability.

3.5. Summary on method

System dynamics is a method that focuses on the study of managerial and dynamic decisions (Forrester, 1961). It makes use of first-order linear and non-linear difference equations to relate qualitative and quantitative factors within and across time periods (Sterman, 2000). This research focuses on building a quantified system dynamics model. This means that the model can be simulated and has as an advantage that the model is formally testable and makes it possible to draw behavioral inferences reliably through simulation (Homer & Olivia, 2001). The validation of a system dynamics model is always relative (Barlas & Carpenter, 1990). The validity highly depends on the explanatory and predictive power of the model (Forrester, 1961). Although the validity of a model is dependent on its goal, it is still possible to test the validity of the model. The logical sequence in which various validation activities must be carried out is: structural tests, structure-oriented behavior tests, and behavior pattern tests (Barlas, 1996).

4. A system dynamics model of the entry deterrence game

In this chapter, the process of building the model is discussed. First, the decision rules for the monopolist and entrant are discussed and later the building of the actual model is discussed more in depth.

4.1. The behavior of the entrant

When looking specifically at the entry deterrence game in extensive form, the entrant first decides whether to enter the market and the monopolist then decides to do nothing, concede, or fight. The entrant will first estimate the chance that the monopolist will fight entry. If the entrant thinks the monopolist will fight entry then the entrant will think twice about entering the market, while if the entrant thinks the monopolist will concede because the monopolist is weak then the entrant will enter the market. The monopolist will do nothing if the entrant does not enter. If the entrant enters then the monopolist must decide whether to take action or not. Fighting entry in one stage of the game can help to deter entry in later stages of the game. After each decision of the monopolist the entrant updates its beliefs about the monopolist according to the game theoretic solution and then decides again what to do based on these updated beliefs. Only when the monopolist concedes, the entrant can be sure that they are dealing with a weak monopolist and will enter in every following stage of the game (Kreps & Wilson, 1982; Boone, Trautmann & Raes, 2013). There is a clear feedback loop in the game, in which each decision influences the next decision that is to be made. However, in the system dynamics model the decision of the entrant is based on the history of the game and not on Bayesian updating. It is unlikely that the entrant will benefit from a solution based on Bayesian updating, because even a weak monopolist will choose to fight if this is more profitable on the long run.

Moreover, the solution proposed by Kreps & Wilson (1982) is debated as well and recent research states that the entrants only enter in the last rounds of the game due to the restrictive assumption that entrants cannot reconsider their decision to stay out when they observe the monopolist's response elsewhere. Without this assumption, all entrants stay out if the probability that the monopolist will fight is high enough (Melles & Nitsche, 2016). Furthermore, an entrant might even enter in such a game even though this might lead to losses on the short term for them. In this case, the entrant hopes that by entering several times the monopolist will concede (Mason & Nowell, 1998). Based on this information, it follows that not all entrants might uphold the same strategy when playing the entry deterrence game. Some entrants might be more willing to take risk than others. In addition, it could be possible that the amount of loss that the entrant is willing to risk develops during the game. Based on these differences the model will explore four different attitudes towards the loss that the entrant is willing to make. These four modes are as follows:

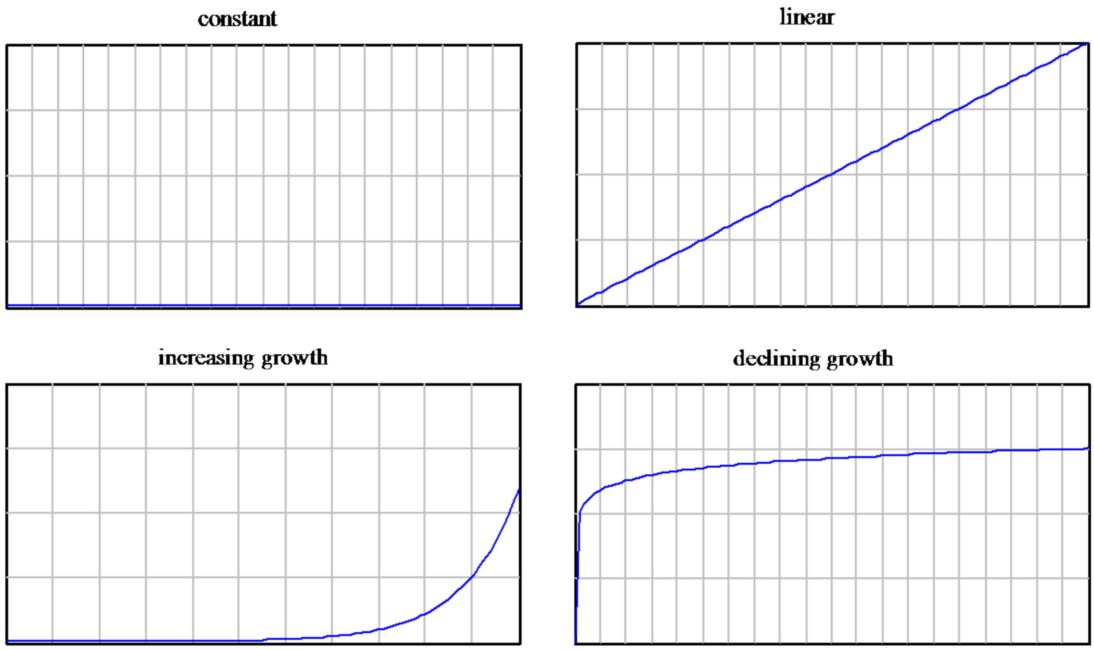


Figure 3. Four attitudes towards risk

4.2. The behavior of the monopolist

If a company has a secure monopoly on a market, it has two options when an entrant is thinking about entering the market. The first option is to be passive and concede. The monopolist allows the entrant to enter the market which will lead to a duopoly. The second option is to fight the entry in the hope of deterring the entry. A rational monopolist will only deter entry if committing to deterrence is more profitable than sharing the market with the entrant. The threat of entry from the entrant is related to the theory of market contestability. A contestable market is a market with low entry and exit costs. In contestable markets the change of entry by another company is larger, since it is easy for firms to enter the market. When determining what the best option is, it is important to look at the long-run. Allowing entrants on the market might be more profitable for the short-run, but in the long-run it can be more profitable to deter entry since allowing entrants on the market will reduce the profit of the monopolist (Boone, Trautmann & Raes, 2013). Consequently, the monopolist will fight entry if the expected payoffs from fighting off entry are higher than conceding. The expected payoffs of fighting are based on the payoff that the monopolist gets in the round that he fights as well as what the monopolist expects to get as payoffs if the fights entry in this stage of the game.

4.3. The system dynamics model

Based on the above-mentioned behavior of the entrant and monopolist the system dynamics model can be made. This model will be explained in several steps: the decision mechanism of the entrant, the calculation of the probability of entry by the monopolist, the decision mechanism of the monopolist, the calculation of the probability of fight by the entrant, and lastly the different attitudes towards risk of the entrant.

4.3.1. The decision mechanism of the entrant

The decision of the entrant relies on the following factors:

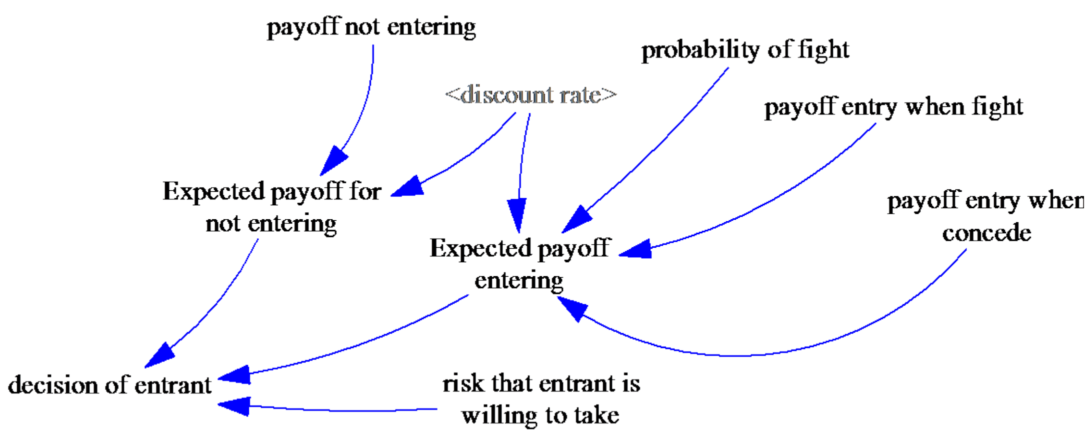


Figure 4. The decision mechanism of the entrant

Based on the probability of fight the entrant will be able to calculate the expected payoff for entering and not entering. For the model, it is assumed that both the monopolist and entrant can expect the payoff at regular intervals and last forever. Meaning, that the expected payoff can be seen as a perpetuity. When making their decision, they will not only take into account the payoff that they get in this particular round, but the expected future cash flows as well.

The present value of a perpetuity can be calculated with the following formula (Berk & DeMarzo, 2014):

$$PV_{perpetuity} = \frac{cashflow}{discount\ rate}$$

Therefore, the entrant determines the expected payoffs for entering as follows:

$$Expected\ payoff\ for\ entering = probability\ of\ fight * payoff\ entry\ when\ fight + (1 - probability\ of\ fight) * payoff\ entry\ when\ concede + \frac{probability\ of\ fight * payoff\ entry\ when\ fight + (1 - probability\ of\ fight) * payoff\ entry\ when\ concede}{discount\ rate}$$

The expected payoff for not entering is equal to the discounted payoff for not entering and the risk that the entrant is willing to take depends on the attitude towards risk which will be discussed in depth later on. The following decision rule then goes for the entrant:

$$decision\ of\ entrant = IF\ THEN\ ELSE\ (-risk\ that\ entrant\ is\ willing\ to\ take < (expected\ payoff\ for\ entering - expected\ payoff\ for\ not\ entering), 1, 0))$$

In this decision rule, 1 stands for entering the market while 0 stands for staying out. If the expected payoff for entering minus the payoff for not entering is higher than the risk that the entrant is willing to take to enter the market, the entrant will enter the market. However, if the costs of entering exceed the risk that the entrant is willing to take, the entrant will stay out. The expected payoff from not entering is considered here, because if the entrant would get more than zero for not entering than the entrant will take this into account in his decision to enter or not. In real life situations, this could be the case if the entrant can use the money that he would else spend on entering the market for other purposes.

4.3.2. The calculation of the probability of entry

The monopolist will base the probability of entry on past decisions of the entrant. The part of the system dynamics model that calculates the probability looks as follows:

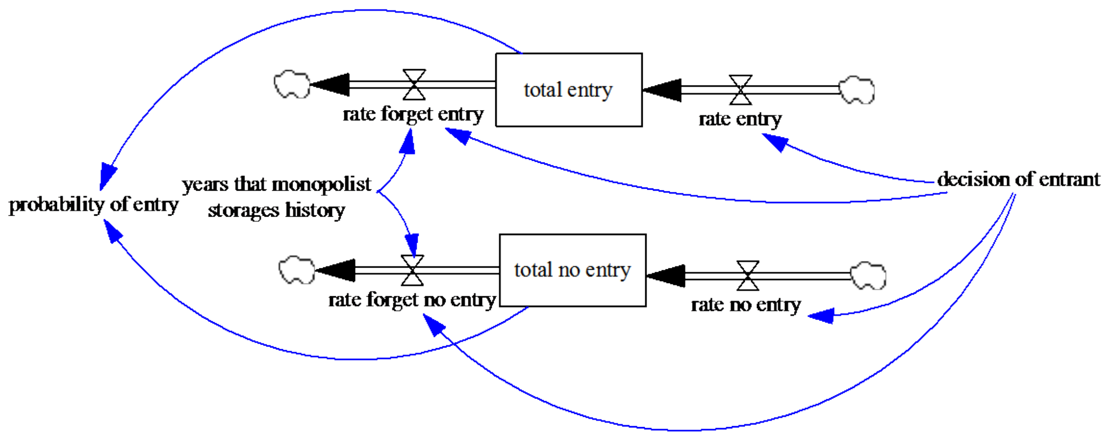


Figure 5. The calculation of the probability of entry

The probability of entry is based on the decisions that the entrant makes during the game. All decisions are accumulated in two stock, so that the monopolist has an overview of the total amount of times that the entrant decided to enter and the total amount of times that the entrant decided to stay out. The rate of entry and no entry are stated as follows:

$$rate\ entry = decision\ of\ entrant$$

$$rate\ no\ entry = ABS(decision\ of\ entrant - 1)$$

Since the value of the decision of the entrant is 1 if they decide to enter the market the rate of entry is equal to the decision of the entrant. For the no entry rate the absolute value of the decision of the entrant – 1 is calculated. The probability of entry is calculated as follows:

$$probability\ of\ entry = \frac{total\ entry}{total\ entry + total\ no\ entry}$$

However, the monopolist is aware that if during the game, they ever concede the probability of entry immediately jumps to 1 since the entrant then knows that they are dealing with a weak monopolist. Therefore, the equation is adjusted as follows to resemble this:

$$probability\ of\ entry = IF\ THEN\ ELSE\ (total\ concede > 1, 1, \frac{total\ entry}{total\ entry + total\ no\ entry})$$

During analysis of the model, it was found out that depending on the entire history of the game can lead to counterintuitive behavior of the monopolist. This behavior is discussed more in depth in the next chapter. Based on these result the variable ‘years that monopolist storages history’ was added. This variable represents the number of years that the monopolist looks into the past to determine the probability that the entrant will enter. The number of years influences the rate by which the monopolist forgets the number of ‘total entry’ and ‘total no entry’. The rates are determined as follows:

$rate\ forget\ entry = DELAY\ FIXED\ (decision\ of\ entrant,$
$years\ that\ monopolist\ storages\ history, 0)$
$rate\ forget\ entry = DELAY\ FIXED\ (ABS(decision\ of\ entrant -$
$1)\ , years\ that\ monopolist\ storages\ history, 0)$

4.3.3. The decision mechanism of the monopolist

The decision of the monopolist relies on the following factors:

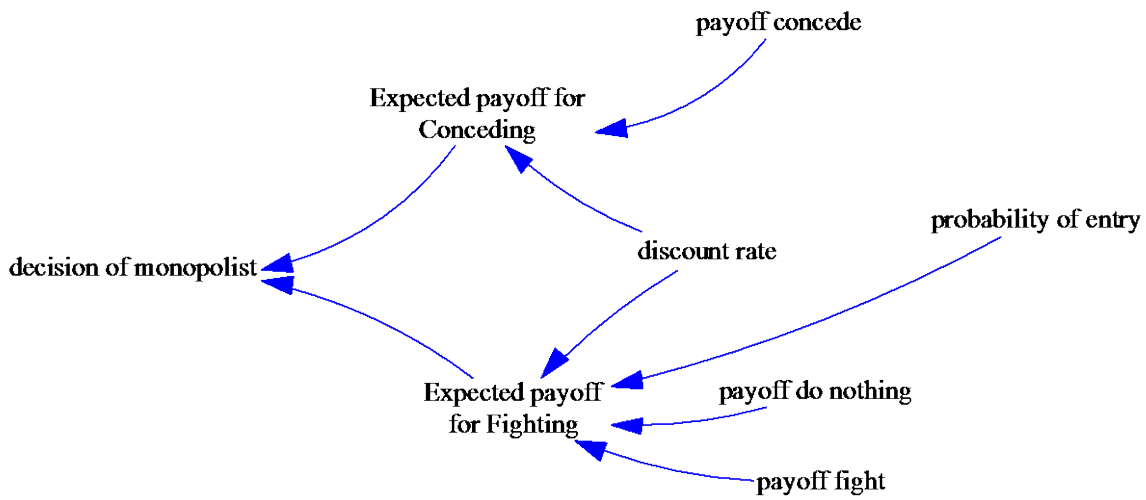


Figure 6. The decision mechanism of the monopolist

While the expected payoff for conceding is constant, the expected payoff for fighting is not since it is based on the probability of entry that is updated each round. Both the expected payoff for conceding and fighting are discounted. This leads to the following expected payoffs:

$$Expected\ payoff\ for\ conceding = payoff\ concede + \frac{payoff\ concede}{discount\ rate}$$

$$Expected\ payoff\ for\ fighting = payoff\ fight + \frac{payoff\ fight * probability\ of\ entry + (1 - probability\ of\ entry) * payoff\ do\ nothing}{discount\ rate}$$

Based on these expected payoffs the monopolist determines their decision to fight or concede as follows:

$decision\ of\ monopolist = IF\ THEN\ ELSE\ (Expected\ payoff\ for\ fighting >$
$expected\ payoff\ for\ conceding, 1, 0)$

In this equation, 1 stands for the decision of the monopolist to fight and 0 stands for concede. If the expected payoff from fighting is higher than the expected payoff from conceding the monopolist will fight off entry in the belief that this is likely to deter entry in later stages of the game. Accordingly, the monopolist will choose to fight if the expected payoff for fighting is higher than the expected payoff for conceding and will concede if this is not the case.

4.3.4. The calculation of the probability of fight

Based on past decisions of the monopolist, the entrant will determine the probability that the monopolist will fight. Therefore, the entrant uses the history of the game. The part of the system dynamics model that represent this looks as follows:

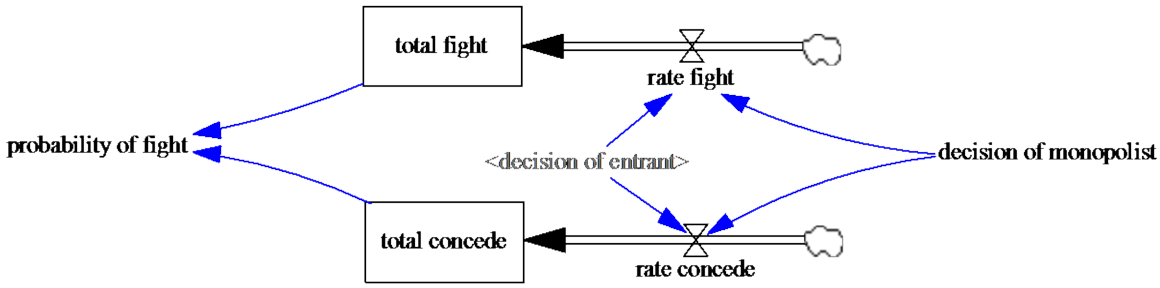


Figure 7. The calculation of the probability of fight

The equations are similar to the above-mentioned equations that are used to calculate the probability of entry. The main difference is that the entrant can only see the decision of the monopolist if the entrant entered the market. Therefore, the rates only work when the entrant decided to enter. This leads to the following equations for the rates:

$rate\ fight = IF\ THEN\ ELSE\ (decision\ of\ entrant = 1, decision\ of\ monopolist, 0)$

$rate\ concede = IF\ THEN\ ELSE\ (decision\ of\ entrant = 1,$

$ABS\ (decision\ of\ monopolist - 1), 0\ )$

Based on the history of the game the probability of fight is then calculated as follows:

$probability\ of\ fight = IF\ THEN\ ELSE\ (total\ concede > 1, 0, \frac{total\ fight}{total\ fight + total\ concede})$

If the monopolist concedes once in the game, then the entrant will know that they are dealing with a weak monopolist and fighting is no longer useful for the monopolist. Consequently, the probability of fight then drops to zero. Until this happens the probability of fight is calculated based on the history of the game.

4.3.5. Different risk attitudes

As stated above the model will take the amount of risk that the entrant is willing to take into account. The model does this by introducing the following elements:

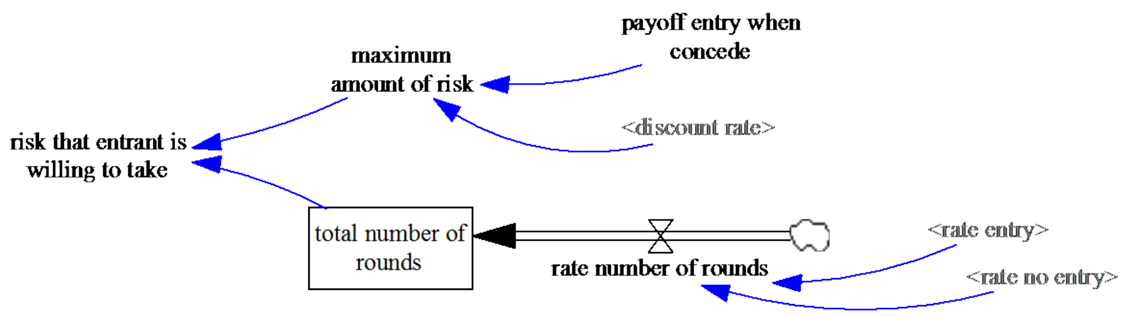


Figure 8. The risk that the entrant is willing to take

When the entrant has a constant amount of risk that they are willing to take then it is not necessary to accumulate the total number of rounds and the risk that the entrant is willing to take will stay constant. Furthermore, the risk that the entrant is willing to take is linked to a maximum amount of risk that is related to the payoff the entrant will get when the monopolist concedes. The maximum amount of risk is calculated as follows:

$$maximum\ amount\ of\ risk = payoff\ entry\ when\ concede + \frac{payoff\ entry\ when\ concede}{discount\ rate}$$

Based on this formula, the maximum amount of risk that the entrant is willing to take will never exceed the amount that the entrant can get if the monopolist concedes from this round on since no rational entrant will be willing to take more risk than they can ever earn in the game. As stated above, four different attitudes towards risk will be analyzed in this model. These four attitudes are: constant, linear, increasing growth, and declining growth. For each of these four attitudes the risk that the entrant is willing to take is based on a different equation. As stated above, in the case of a constant amount of risk the variable will remain constant and will be a fixed number that cannot exceed the maximum amount of risk. In the case of the other amounts of risk the following formulas will be used:

$$linear = MIN(x * total\ number\ of\ rounds, maximum\ amount\ of\ risk)$$

$$increasing\ growth = MIN(0{,}0001 * x\hat{}total\ number\ of\ rounds, maximum\ amount\ of\ risk)$$

$$declining\ growth = MIN(LOG(total\ number\ of\ rounds + 0.0001, x), maximum\ amount\ of\ risk)$$

In which x will be chosen in such a way that all three formulas have about the same value in the hundredth round of the game. Since both the logarithmic and growing function cannot start from zero, a very small number is used as a base in these formulas.

4.3.6. An overview of the complete model

Based on the above-mentioned loops, the complete model looks as follows:

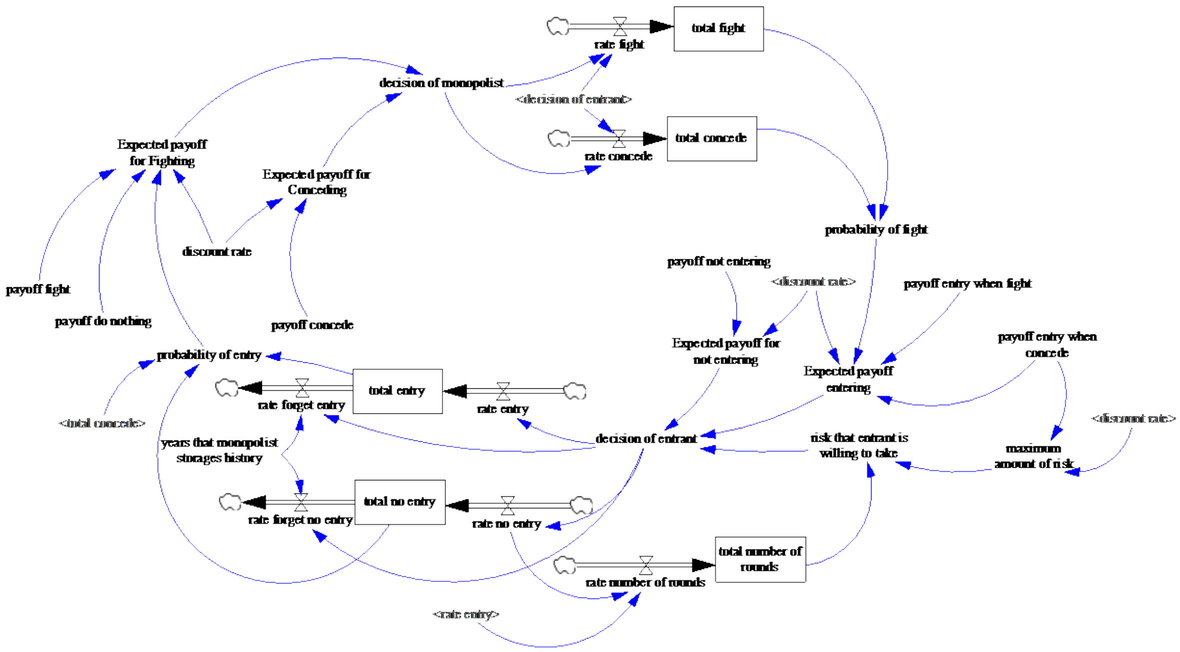


Figure 9. The system dynamics model on the entry deterrence game

5. Analysis of the model

In the model the payoffs are set as follows for the analysis:

	Entrant	Weak Monopolist
Entry followed by fight	-0.5	-1
Entry followed by concede	0.5	0
Entrant stays out	0	2

Table 2. Payoffs in the model

5.1. Constant amount of risk

If the risk that the entrant is willing to take is stable and does not alter during the game then the course of the game entirely depends on the amount of loss that the entrant is willing to take and the payoffs for the players. As a result, the entrant is likely to never enter during the game if they are not willing to take any risk and the probability that the monopolist will fight is sufficiently high so that the expected payoff from entering is not higher than the expected payoffs from staying out. Furthermore, if the risk that the monopolist is willing to take is high enough then the entrant will immediately enter in the first stage of the game and will not wait until later rounds in the game. Moreover, if at any point the probability that the monopolist is strong is sufficiently high enough the entrant will not enter anymore. If the monopolist in fact would be strong then this would result in an entrant that would enter for a number of rounds until the entrant thinks that the probability that the monopolist will fight is so high that the expected payoffs from entering minus the expected payoffs from staying out are higher than the risk that the entrant is willing to take to secure a place on the market. However, if the risk that the monopolist is willing to take is high enough then it is likely that the weak monopolist will concede after a while, depending on the payoffs of the monopolist.

5.2. History

While for analysis of the constant amount of risk this was not seen, simulation based on the other forms of risk show that it can be paradoxical for the monopolist to base their decision on the entire history of the game. When the amount of risk that the entrant is willing to take develops during the game then the entrant will be more willing to enter the market as the game progresses and after a certain number of rounds the entrant will even enter constantly.

Which leads to the following behavior of the entrant when the risk that the entrant is willing to take is based on the following formula: $0.21 * total\ number\ of\ rounds$.

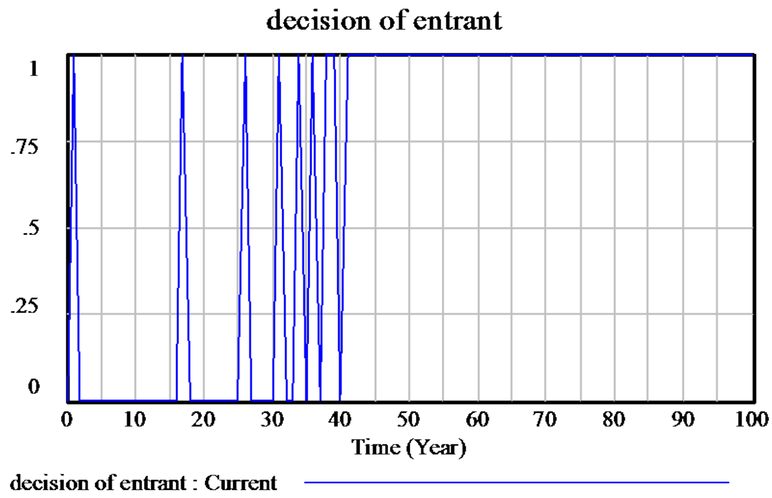


Figure 10. Decision of entrant

Based on the decision that the entrant is making, it seems that the monopolist should concede somewhere after round 40. However, if the monopolist bases the probability that the entrant will enter on the entire history of the game then it takes a very long time until the probability that the entrant will enter is high enough for the monopolist to calculate the expected payoffs from fighting in such a way that they are lower than the expected payoffs from conceding. The development of the probability that the entrant will enter looks as follows:

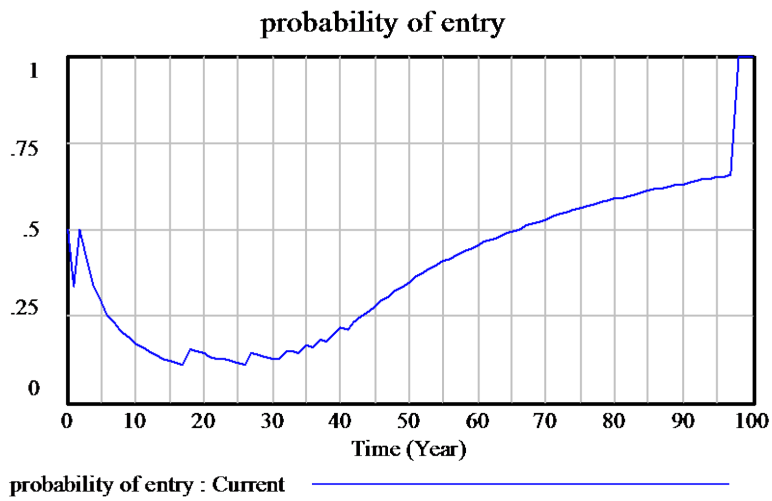


Figure 11. Probability of entry

The probability of entry jumps to one as soon as the monopolist concedes, because then the entrant will most definitely always enter since the entrant then knowns that the monopolist is weak. From this it follows that if the monopolist would base the probability on the entire history of the game this would lead to irrational behavior of the monopolist, because the monopolist is making a considerable loss by fighting off entry while it clearly no longer can deter entry. It is therefore likely that if the entrant adjusts the amount of risk that it is willing to take during the game the monopolist will not base the probability that the entrant will enter on the entire history of the game, but rather only on recent history. When the monopolist for example only uses the past 20 rounds to determine their choice, the probability of entry develops as follows:

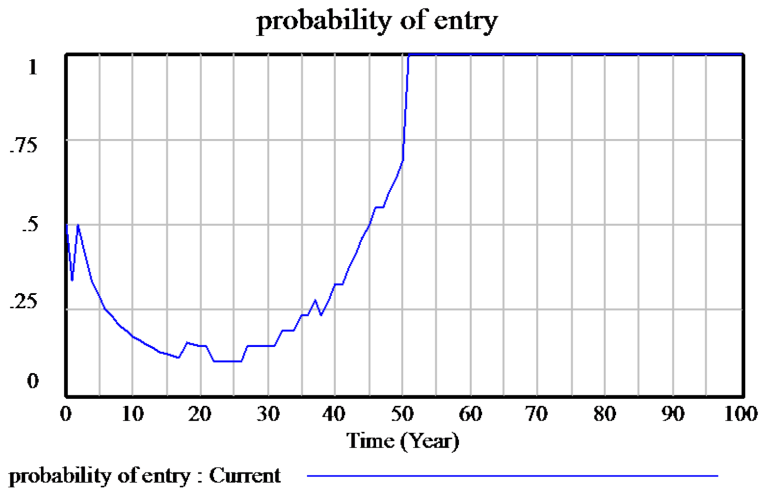


Figure 12. Probability of entry

Clearly, if this decision is based on recent history then the monopolist will concede much earlier in the game. For the rest of the analysis the number of rounds that the monopolist storages to base the probability of entry on is therefore taken into account.

5.3. Linear and growing risk

While the analysis with the constant amount of risk is very different, the other three forms of risk are more similar. That is, both three forms of risk develop during the game. Therefore, the equations for the amount of risk are in all three cases determined in such a way that they lead to approximately the same value in the 100th round of the game. For the analysis of this model this value was set equal to the discounted payoff for entry followed by fighting. So, in the 100th

round of the game the risk that the entrant is willing to take is equal to 10.5. The amount of risk is based on the following three equations:

$$linear = 0.105 * total\ number\ of\ rounds$$

$$increasing\ growth = 0{,}0001 * 1.1226\hat{}total\ number\ of\ rounds$$

$$declining\ growth = LOG(total\ number\ of\ rounds + 0.0001, 1.5)$$

Based on these three equations, the following behavior can be observed if the monopolist bases their decision on the past twenty years and the discount rate is set at 5%:

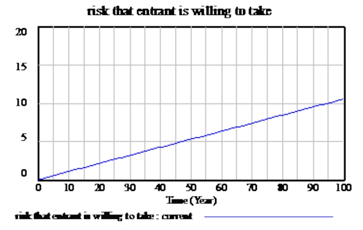
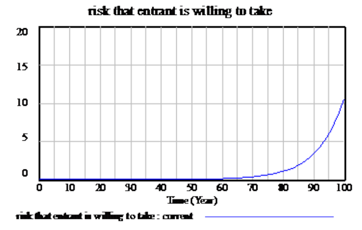
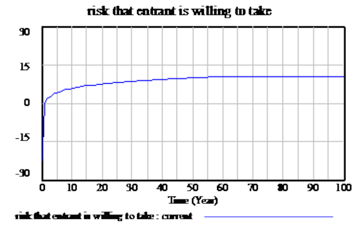
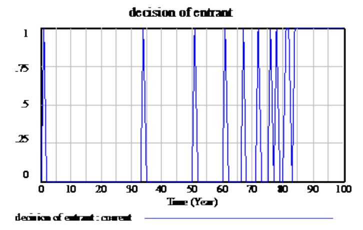
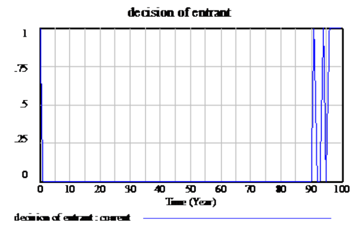
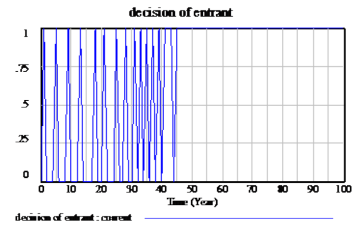
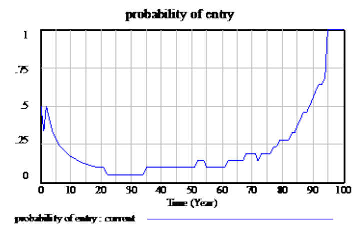
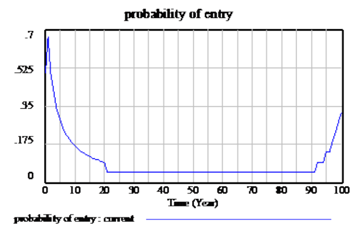
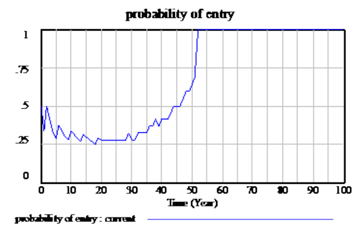
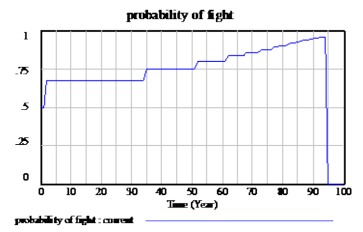
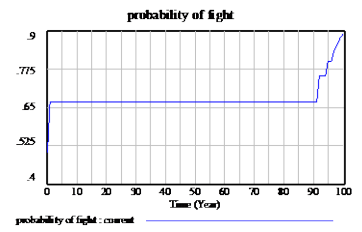
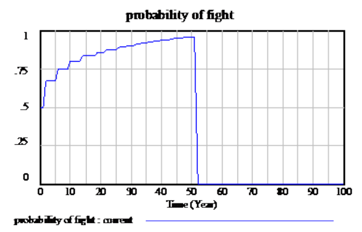
	Linear	Increasing growth	Declining growth
Risk:			
D. Entrant:			
Prob. entry:			
Prob. Fight:			

Table 3. Results of simulation of different attitudes towards risk

Logically, if the model is extended over a longer period of time, at some point the monopolist will concede as well in the model of increasing growth. An interesting difference is that there is a difference in the number of times that the monopolist fights off entry before conceding. Besides, the entrants clearly differ in the number of rounds that it takes them before entering the market. While in the model with declining growth for risk the entrant is fought off more times than in the other models, the monopolist concedes much sooner than in the other markets. If there is too much time between entries the monopolist will fight off entry for a longer time, because it takes more time for the monopolist to update the probability that the entrant will enter to a level at which it is better for them to concede. However, although some attitudes lead to less fighting on behalf of the monopolist, they might not be the most profitable attitude for the entrant to choose, because it takes much longer for the monopolist to concede.

6. Validity of the model

As stated in chapter three there are three different types of validity tests: structural tests, structure-oriented behavior tests, and behavior pattern tests. All three of these tests will be used to determine the validity of the model in this chapter.

6.1. Structural validity

The structural validity test can be tested with the structure verification test, parameter verification test, extreme condition test, boundary adequacy, and dimensional consistency test (Forrester & Senge, 1980). The structure verification test, parameter verification test, and extreme condition test did not lead to any alterations to the model. The model structure is in line with what is known about the structure of the real system; that there is a loop in which each decision is based on the previous decision of the other player. Furthermore, each parameter matches an element in the real system and their values lie within plausible ranges. The payoffs that are used in the model are based on the payoffs that can be derived from a generalized version of the entry deterrence that can be found in Carmichael (2005). Moreover, the model still behaves plausible under extreme values and the maximum risk that the entrant is willing to take can never exceed the amount that a rational player is willing to take. Based on the boundary adequacy test the model was altered in such a way as to include the time that the monopolist stores history. Based on the counter intuitive behavior that was gained from analysis there was the doubt that something was missing. Based on this doubt structure was added so that the monopolist would only store the history for a certain number of years. This alteration had great influence on the model and made sure that the monopolist would concede much sooner if the behavior of the entrant changed during the game. Lastly, the dimensional consistency test was conducted. Vensim has a 'units check' function that was used to test this. The tests stated that the equations are dimensionally consistent. Based on all these tests it should be mentioned that there is one aspect of the real world that is not considered in the model. In the real world both the monopolist and entrant are likely to have limited funds. Based on these limits funds an entrant might go bankrupt after entry is followed by fight or the monopolist might not have enough funds to fight of entry. Such a limitation could lead to the monopolist conceding earlier in the game or to the entrant never entering if their funds run out before the monopolist concedes.

6.2. Structure-oriented validity

Due to the nature of the model not all structure oriented tests are of importance. The tests conducted for the model are the pattern/event prediction test, anomaly test, family member test, surprise behavior test, and sensitivity test. The pattern/event prediction test, anomaly test, and surprise behavior test did not lead to any alterations to the model. The behavior that is predicted by the model is plausible in the real system. Although the behavior that an entrant who is not willing to take any risk or has a low constant amount of risk stays out if the probability that the monopolist will fight is high enough might seem surprising, the observed behavior is in line with research from Melles & Nitsche (2016). Lastly, the sensitivity test was conducted in Vensim. Different model inputs were altered and the range of outputs that were generated was observed. Since the model is made with a free version of Vensim, Vensim PLE, the sensitivity analysis cannot be conducted automatically by Vensim. Therefore, the test was conducted with the help of the 'SyntheSim' function in Vensim. This function allows the modeler to make changes in their parameters while immediately observing the behavior. During the analysis, it was clear that changing parameters values influences the behavior in the model, but that the overall behavior mode remains. The discount rate has little influence on the decision of the monopolist:

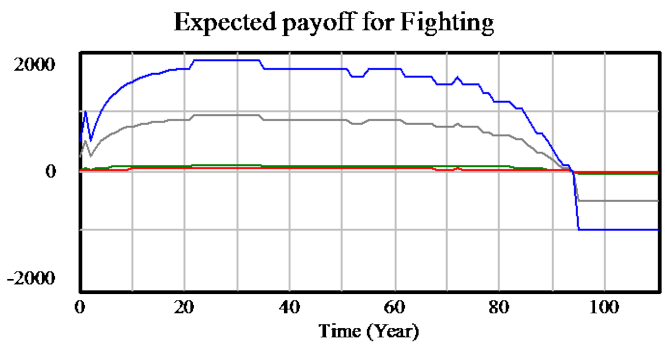


Figure 13. Multiple runs of expected payoff for fighting

This is the result of run in Vensim in which the discount rate varies between 0.1% and 8%. Clearly, the discount rate has little influence on the moment that the expected payoff for fighting become negative. This is not the case for alterations in payoffs or the years that the monopolist stores history. If the monopolist stores history longer then it will take longer for the monopolist to concede. Moreover, if the payoffs are altered then this can influence the decision that the entrant and monopolist make. Although in the model this is not a separate parameter, the risk that the entrant is willing to take is crucial for the model as well. The less risk that the entrant is willing to take per round, the longer it will take before the entrant will enter consecutively and thus for the monopolist to concede. Consequently, the payoffs, the risk the entrant is willing to take, and the years that the monopolist stores the history of the game, influence the moment at which the entrant will enter and the monopolist concede. However, as long as the basic assumptions of the model are in place, at some point the monopolist will concede. These assumptions are that the risk the entrant is willing to take is increasing over time and that entering the market when followed by concede will lead to a profit for the entrant.

6.2.1. Behavior pattern validity

For behavior pattern validity, the plausibility test and consistency test were conducted. In the plausibility test the model is ran to the end of simulation to test if it is going in the right direction. Running the model for 1000 rounds showed that this is not a problem. After the monopolist concedes once the monopolist no longer fights, no matter how long the simulation lasts. The other test that was conducted is the consistency test. The consistency test checks that if the model is run more than once it still produces the same results and if the model is duplicable. Running the model over and over did not give any different results. Although no validity problems arise from the plausibility and consistency test, the model clearly lacks validity when it comes to the observed behavior in the model. There is no reference mode of behavior that the model tries to capture and therefore it is impossible to validate the model in this way.

7. Conclusion & discussion

This chapter contains the conclusion and the discussion. In the conclusion, the main research question will be answered based on the results of this research. In the discussion, the validity of the research and opportunities for further research will be examined.

7.1. Conclusion

The central research question of this research was:

What are the dynamic mechanisms in the iterated entry deterrence game?

This main research question was divided into several subquestions that have been answered during this research. Furthermore, a system dynamics model of the entry deterrence game was built and analyzed to help answer the research question.

The entry deterrence game is greatly known for the paradox of backward induction. This paradox follows from analyzing the last round of the game first and then using backward induction to work back to the first round. Since backward induction relies on players' belief about what they later will believe, this is not a suitable method for a system dynamics approach. In system dynamics, it is assumed that the true future is not known to anyone and future information can therefore not be taken into account. Moreover, it was already stated that such a chain of beliefs cannot be comprehended by a player (Bacharach, 1992).

The system dynamics model tries to represent the real world. Therefore, the solution to the entry deterrence game of Kreps & Wilson (1982) was modeled. In their solution, there is incomplete information about the monopolist pay-offs. According to Kreps & Wilson, the entrant determines if the monopolist is weak or strong through Bayesian updating. However, the system dynamics model showed that it is not possible to solve this game through Bayesian updating since even a weak monopolist will choose to fight if the probability that the monopolist will enter is low enough. Instead, both the monopolist and entrant will base their decision on the history of the game.

Clearly, the dynamic mechanisms in the iterated entry deterrence game consist of both the entrant and the monopolist who make decisions over time which are affected by past decisions. The decisions that the monopolist and entrant make are stored in the history of the game. Based on the history of the game the probability of entry and the probability of fight are determined. The monopolist and entrant then use this probability to calculate their expected payoffs in the game and make their decision based on these expected payoffs. Moreover, for the entrant another important factor is the amount of risk that the entrant is willing to take to enter the market. If the entrant is not willing to take any risk, then the entrant will not enter the market if the probability that the monopolist will fight is sufficiently high. This result is in line with earlier research conducted by Melles & Nitsche (2016). The entrant will only be able to enter the market if the amount of risk they are willing to take is sufficiently high.

The model explored both a constant amount of risk for the entrant and an amount of risk that developed over time. While the above applies both to the stable and developing amount of risk, the model in in which the amount of risk developed over time provided some extra insights. While all three modeled attitudes towards risk were able to enter the market successfully at some point in the game, the amount of time that it took them and the number of times that they were fought varied greatly. The declining growth model was fought most often followed by the linear and increasing growth model. The increasing growth model took the longest time to enter the market successfully followed by the linear and declining growth model. Although the declining growth model for risk was fought more often by the monopolist, the entrant entered the market sooner which on the long term is more profitable. Nonetheless, a high enough stable amount of risk will always be more successful, because the sooner the entrant enters consistently the sooner a weak monopolist will concede.

To conclude, the results of this study are not in line with the theoretical game theory solutions. Moreover, Bayesian updating does not work as a solution in the system dynamics model since a weak monopolist will try to fight off entry as well. According to game theory the subgame perfect Nash equilibrium of the game is entry followed by concede. However, the system dynamics model shows that this is not always the outcome of the game. Besides, it can take a long time to reach the Nash equilibrium, entry followed by concede. The entrant will only enter the market if the amount of risk that the entrant is willing to take is high enough. This amount of risk needs to be higher than the expected loss of entering. If the entrant is not willing to take this amount of risk, then the entrant will not enter if the probability that the monopolist is strong is sufficiently high. In addition, the sooner the entrant consistently enters the market the sooner the monopolist will concede.

7.2. Discussion

The discussion contains a methodological reflection, and recommendations for both theory and practice.

7.2.1. Methodological reflection

The methodological reflection encompasses the validity and limitations of this research. This research focuses on answering the main research question by simulating a system dynamics model. The goal of the research was to uncover the dynamic mechanisms in the iterated entry deterrence game with the help of a system dynamics approach. The validity of the study can be divided into internal and external validity. Internal validity refers to the quality of the research design, while external validity refers to the transferability of the results of this study to reality. In general, system dynamic models are simplified representations of reality. The validity of system dynamic models is seen from a relativist point of view. A system dynamic model is just one of many representations of reality and model validation is the gradual process of building confidence in the model's usefulness (Barlas & Carpenter, 1990). In other words, the validation process of system dynamic models is an iterative process in which various tests are used to scrutinize the model and gain confidence in its usefulness. The tests that were used to validate this model are described in chapter 6. As stated before, the main validity problem for this model is that there is no reference mode of behavior. Likewise, from the model it follows that there are still parts of the reference system that are not fully understood. These will be discussed more in the next subchapter, namely recommendations for theory. Moreover, this model assumes unlimited funds for both the monopolist and entrant. In practice, it is likely that this will not be the case and that this could influence the monopolist's and entrant's decision. However, these limitations do not mean that this model is not useful. The model still has great explanatory power. Although it has its limitations, the model provides clear insight into the dynamic mechanisms of the iterated entry deterrence game and the solution of the model provides a plausible alternative for the theoretical game theory solution.

7.2.2. Recommendations for theory

The system dynamics model contradicts the theoretical game theory results for the entry deterrence game. Furthermore, based on the system dynamics model Bayesian updating is not a viable solution method for the game. As stated before, a weak monopolist is willing to fight off entry if on the long-run this is more profitable (Boone, Trautmann & Raes, 2013). Consequently, Bayesian updating will not work, because as long as the expected payoffs from fighting are high enough the probability that the weak monopolist will fight is equal to 1.
There are several areas that could be explored for further research. In general, this research once again proves that the modelling of game theory models with system dynamics is worthwhile. By letting go of game theoretical assumptions and instead following system dynamic principles, different solution concepts can be found for games. Consequently, this could lead to new insight. Additionally, it is likely that not all game theory assumptions hold up in the real world.

Based on the system dynamics model there are some elements of the system dynamics model that need to be examined more closely. Related to the entrant the main area in need of exploration is how the entrant determines if they are willing to take risk and if and how this amount develops over time. It makes sense that an entrant is willing to take risk, since if the monopolist is in fact weak the entrant can make a profit on the long-term by accepting a loss on the short-term. However, it is still unclear how the entrant exactly determines the risk that they are willing to take. Consequently, further research should be carried out to establish more confidence in the system dynamics model. An experiment in which entrants and monopolist have the same information available as in the system dynamics model could be conducted to test whether they behave in a similar fashion as in the model.

7.2.3. Recommendations for practice

Although this model mainly focused on theory it provides some valuable insight for practice as well. In practice, existing firms often deliberately try to deter the entry of other firms

(Edwards, 1955). The system dynamics model provides insight in the rationale behind these strategies and the behavior that the entrant could follow.

Based on the system dynamics model it is clear that for the monopolist it is worthwhile to fight entry in some cases. Especially if the entrant is not willing to take any risk or only a small amount, the entrant will not enter if the probability that the monopolist is strong is high enough. Hence, fighting pays off in this case. In addition, the monopolist can deter entry for at least some time if the entrant has a risk attitude that develops over time. In this case, it can still payoff for the monopolist to fight off entry, because during the time that they remain a monopolist and entry is deterred their profits are higher than when they allow the entrant on the market. If the entrant has, however, a risk attitude that develops over time then it would be smart for the monopolist to not base their decision on the entire history of the game. If they do this, then it will take considerably longer for the monopolist to update the probability of the entrant to a sufficiently high level for the monopolist to concede. This results in paradoxical behavior, since the monopolist is fighting the entrant for a very long time even though it is clear that the entrant will consecutively enter. When it comes to the entrant, the research has shown that entering consecutively is the best option for the entrant. The sooner the entrant answers consecutively, the sooner the weak monopolist will update their beliefs about the entrant and concede.

8. References

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Appendix I: Structure of system dynamic models

This appendix contains information about the structure of system dynamic models.

Components of system dynamic models

System dynamics originally consisted out of four foundations: simulation technology, computing technology, strategic decision making, and the role of feedback in complex systems (Forrester, 1958; Forrester, 1961). Over time the foundations of system dynamics were, however, expressed differently. The focus was no longer on the four foundations that inspired Forrester to come up with system dynamics, but shifted to the structure of the approach. System dynamics makes use of a four-tiered structural hierarchy that looks as follows (Forrester, 1968a):

- Closed boundary around the system
    - Feedback loops as the basic structural elements within the boundary
        - Stock variables representing accumulations within the system
        - Flow variables representing activity within the system
            - Goal
            - Observed condition
            - Detection of discrepancy
            - Action based on discrepancy

The first hierarchical level is the closed boundary around the system. The second hierarchical level are the feedback loops that form the basic structural elements within the boundary. At the third hierarchical level are the stock and flow variables. The fourth level consists of the substructure of the flow variables. Each substructure of a flow variable consists of the goal of a decision-making point in the system, the observed condition, a means for detecting a discrepancy between the goal and the observed condition, and the desired action in case of a discrepancy (Forrester, 1968b).

Closed boundary

The concept of the closed boundary entails that when building a model one should always ask the question where the boundary is. When determining the boundary of a system it is important to determine the boundary in such a way that within the model the smallest number of components are included that allow the dynamic behavior to be studied (Forrester, 1968a). This does not mean that from the system that is being modelled, nothing goes beyond the boundary, but signifies that what is outside the boundary of the system is not important for studying the problem at hand. Hence, variables that lie outside the system boundaries do not create the causes and symptoms of the behavior that is being modelled (Forrester, 1968b). The concept of the closed boundary thus implies that the system behavior is generated within the boundary and not imposed from outside (Forrester, 1969). From the first hierarchy, the closed boundary, it follows that system dynamics upholds an endogenous point of view. Consequently, system dynamics focuses on uncovering and understanding endogenous sources of system behavior (Richardson, 2011).

Feedback loops

As stated before, system dynamics has an endogenous view. The dynamic behavior of variables is generated within the system. Based on the endogenous point of view, all causal influences should be included in the model to form feedback loops. Without these feedback loops, causal forces would come from outside the system boundary. Feedback loops thus enable the endogenous point of view and give it structure (Richardson, 1991). Accordingly, feedback loops are the basic structural elements of systems. Within these loops every decision is made. Furthermore, every decision that is made interacts with the existing condition of the system and influence the condition of the system (Forrester, 1968b).

Stock and flow variables

Stock and flow variables are two significant components of system dynamics models. Stock variables describe the condition of the system at any moment in time. The flow variables change the values of the stock variables. Stocks are variables that accumulate the effects of flows (Forrester, 1968b).

The distinction between stock and flow variables is crucial when modelling. A stock is always an object that can be captured in time. If one is to take a snapshot of a moment, then everything that is on such a picture is a stock. Consequently, a stock is an amount that exists at a specific point in time. Stock can be physical or non-physical. Physical stocks are natural stock, capital stock, and goods-in-process and use. Non-physical stocks are information (knowledge), psychological passion (human emotion), and indexed figures (Yamaguchi, 2000).

Changes in stocks are described as flows. While a stock is defined at a moment of time, this is not the case for flow variables. A flow is always defined over a period of time. A flow is the increment or decrement of stock during a unit interval. Any dynamic movement can be operatively understood in terms of stock and flow relation. Since a flow is part of a stock, the quantitative unit of flow and stock must coincide. There are many different kinds of flow variables possible. Flows can be discrete or continuous, and autonomous or stock-dependent. In the latter case, the value of the flow is determined by the stock itself (Yamaguchi, 2000).

The substructure of flow variables

The equations of flow variables are the policy statements in a system. The equation entails the rules whereby the state of the system determines action. A policy statement is always made up out of four components: goal, observed condition, detection of discrepancy, and action based on discrepancy. These four components together form the fourth hierarchical level of system dynamic structures. The goal is the objective towards which the system is striving. The observed condition consists of the information inputs on which the decision-making process is based. The observed condition of a system is not necessarily in line with the true state of a system. Any system can be delayed, distorted, biased, depreciated, or contaminated. Thus, the decision is not based on the true state of the system, but on an apparent state. After observing the apparent condition of a system, the policy determines the discrepancy between this state and the goal, and defines the desired action that should be taken to close the discrepancy (Forrester, 1968b).

Appendix II: Model Equations

(01) decision of entrant = IF THEN ELSE(-risk that entrant is willing to take < (Expected payoff entering - Expected payoff for not entering), 1, 0)

Units: Dmnl/Year

(02) decision of monopolist = IF THEN ELSE(Expected payoff for Fighting > Expected payoff for Conceding, 1, 0)

Units: Dmnl/Year

(03) Discount rate = 0.05

Units: Dmnl

(04) Expected payoff entering = probability of fight * payoff entry when fight + (1 - probability of fight) * payoff entry when concede

Units: Dmnl

(05) Expected payoff for Conceding = payoff concede + payoff concede/discount rate + (payoff concede + payoff concede/discount rate) / discount rate

Units: Dmnl

(06) Expected payoff for Fighting = payoff fight + (payoff fight * probability of entry + (1-probability of entry) * payoff do nothing)/discount rate

Units: Dmnl

(07) Expected payoff for not entering = payoff not entering + payoff not entering / discount rate

Units: Dmnl

(08) maximum amount of risk = payoff entry when concede + payoff entry when concede/discount rate

Units: Dmnl

(09) payoff concede = 0

Units: Dmnl

(10) payoff do nothing = 2

Units: Dmnl

(11) payoff entry when concede = 0.5

Units: Dmnl

(12) payoff entry when fight = -0.5

Units: Dmnl

(13) payoff fight = -1

Units: Dmnl

(14) payoff not entering = 0

Units: Dmnl

(15) probability of entry = IF THEN ELSE(total concede > 1 , 1, total entry/(total entry + total no entry))

Units: Dmnl

(16) probability of fight = IF THEN ELSE(total concede > 1, 0, total fight/(total fight + total concede))

Units: Dmnl

(17) rate concede = IF THEN ELSE(decision of entrant = 1, ABS(decision of monopolist - 1), 0)

Units: Dmnl/Year

(18) rate entry = decision of entrant

Units: Dmnl/Year

(19) rate fight = IF THEN ELSE(decision of entrant = 1, decision of monopolist, 0)
Units: Dmnl/Year

(20) rate forget entry = DELAY FIXED(decision of entrant, years that monopolist storages history, 0)
Units: Dmnl/Year

(21) rate forget no entry = DELAY FIXED(ABS(decision of entrant - 1), years that monopolist storages history, 0)
Units: Dmnl/Year

(22) rate no entry = ABS(decision of entrant - 1)
Units: Dmnl/Year

(23) rate number of rounds = rate no entry + rate entry
Units: Dmnl/Year

(24) risk that entrant is willing to take = MIN(0.105 * total number of rounds, maximum amount of risk)
Units: Dmnl

(25) total concede = INTEG (rate concede, 1)
Units: Dmnl

(26) total entry = INTEG (rate entry - rate forget entry,1)
Units: Dmnl

(27) total fight = INTEG (rate fight, 1)
Units: Dmnl

(28) total no entry = INTEG (rate no entry - rate forget no entry, 1)

Units: Dmnl

(29) total number of rounds = INTEG (rate number of rounds, 0)

Units: Dmnl

(30) years that monopolist storages history = 20

Units: Year

(31) TIME STEP = 1

Units: Year

The time step for the simulation.