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Master Thesis

Designing tariffs in a competitive energy market

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Abstract

Energy markets are undergoing major changes right now. The markets have been liberalized and Smart Grid elements are about to be implemented. The energy markets are complex markets, which are difficult to model using traditional economic models. Therefore agent-based models offer solutions. Power TAC attempts to model these energy markets. By using Power TAC new insights in future energy markets can be obtained. We focus on the tariff market of Power TAC. For this market we have created a simulation environment and a specific agent. This agent classifies tariffs and it can identify tariffs that are performing well. It is also capable of analyzing the tariffs of other brokers and the agent can copy and publish an adjusted version of a tariff of a competing agent. The actions taken by this agent depend on specific imbalance scenarios. We have used several scenarios to test our agent and our results indicate that our agent performs well in a competitive market.

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Chapter 1

Introduction

1.1 Motivation and background

The twenty-first century is likely to be a new era for energy. Traditional energy sources are likely to become less important and the use of renewable energy will probably increase. "Smart grid" components that can record and help customers to manage their energy usages will likely be implemented [16]. In the past few years the energy markets have been liberalized and the increased competition can have benefits for consumers [10]. It is important to study the energy market well, since this could give us an idea about the functioning of this market in the 21st century. There have been several studies that studied energy markets for electricity [21, 23], but few studies have investigated the entire energy market.

Power TAC [13] offers an ability to study the entire market. In Power TAC a broker has possibilities to offer energy tariffs, to trade energy on a wholesale market and to negotiate contracts between brokers and customers. The brokers are made by several participants and they participate in the Power TAC game with the hope of winning it. These brokers are thus created in a competitive way and this allows us to study energy markets in a way that has not been done before.

Power TAC consists of several components. In this thesis we focus on tariff markets. There is plenty of literature about the structure of different types of tariffs, but the literature about tariffs in competitive markets is lacking. It is thus interesting to analyze this subject.

In creating a specific agent for this we need to take several aspects into account. First, we need to realize that there are different types of customers, which might each have their own specific preferences. We also need a system that can recognize successful tariffs and unsuccessful tariffs, so that the unsuccessful tariffs can be improved. It should also be possible to make a profit with the offered tariffs, which means that consumption tariffs should in general be higher priced than production tariffs, since energy needs be sold at a higher price to make a profit. High imbalances should be avoided, although the focus on the tariff market should be on consumers, because energy is often bought at the wholesale market and many imbalances can be solved on that market. We also need to take the tariffs of other brokers into account, because the tariffs that we want to offer need to be competitively priced in comparison with the tariffs of the competition. We have taken this considerations into account when we created our agent.

1.2 Contributions

This thesis contributes to the development of strategies for tariffs in agent-based electricity markets. There have been several studies that investigated the wholesale market, but there have been few studies that studied the tariff market in a competitive setting. Our goal is to investigate strategies for this side of the market. We have created an agent with a method for managing strategies. Our method identifies successful tariffs by analyzing several properties of tariffs. Our approach also takes the customer types attracted by tariffs into account. Our method can use this information in copying and altering the tariffs of other brokers. By using this approach, we demonstrate that we can make a successful energy broker if this broker takes known market information, such as the development of the other brokers' tariffs or the type of customers attracted to certain tariffs, into account. As far as we know there have been none studies that used this approach and therefore this thesis contributes to the development of strategies for managing tariffs. Our method is also able to function as a good strategy in Power TAC. Since few strategies for Power TAC are known, our strategy contributes to the developments of strategies in Power TAC.

1.3 Thesis outline

The organization of this thesis is as follows. Chapter 2 includes a literature review of the relevant work for our thesis. In this review, we create an overview of work that has been done in the area of electronic energy markets, other type of TAC games, and energy tariffs. Chapter 3 describes the Power TAC platform and the status of the Power TAC sever during several moments of its development. Chapter 4 describes a Simulation Framework that we have designed to test our agent.

Chapter 5 describes the framework of our agent. This framework includes methods for classifying tariffs, giving scores to tariffs and copying and adjusting competitor tariffs. Chapter 6 includes the experiments of our thesis and it also has a conclusion and discussion about the results of these experiments.

Chapter 7 is the last chapter of our thesis. It includes a conclusion of this thesis and it also gives directions for future research.

Chapter 2

Literature review

To get an idea about how to create a functioning energy broker, we need to review the relevant literature. This chapter is divided into several sections. The first section discusses Agent-based energy markets, which could give us an idea of how agent-based energy markets are structured. The second section discusses TAC games, which are discussed to get an idea of strategies in these type of games. The third section discusses several types of tariffs and since strategies for creating good performing tariffs are the focus of this Thesis, this section is important. The last section gives a conclusion about the related work that has been done in the area of this Thesis.

2.1 Agent-based energy markets

North et al. created an agent-based simulation of an electric power system with the producers and consumer that work in it [17]. The agents objectives were characterized by a utility function and it tested regulatory functions with genetic algorithms. A specific complex adaptive system approach was used to represent the agent's learning and adaptation capabilities. The electronic market was focused on the wholesale market and the bilateral contracts between energy suppliers and energy consumers and not on the tariff market. The structure of the bilateral contracts was not discussed extensively. Many details about the implementation of the system were also missing. The purpose of this study was to create an e-laboratory where regulatory structures can be tested before they are applied to real systems and initial test runs of this systems seem to demonstrate that this is possible, because EMACS managed to replicate the original market game and therefore new regulatory structures can be tested by changing these structures in the framework. The goal of this paper is thus different than the goal of this thesis, because in this thesis the focus is more on developing successful strategies in the tariff market and our goal is not to simulate the wholesale market and we also do not want to simulate new regulatory structures in energy markets.

Sueyoshi et al. created an agent-based decision support system for the wholesale energy market [19]. This system consisted of 5 agent types and it simulated the market in real time and the market of a day ahead. Both power companies and the wholesalers had the opportunity to make bidding decisions by using a custom-made adaptive learning algorithm that analyzed historical data of the wholesale market and the specific information of the wholesaler or the power company, such as generation capacities or demand forecasts. The system also included capabilities for estimation, transmission, decision making and analyses. The authors showed that their system could analyze the dynamic price changes in the US during the Californian energy crisis. This demonstrated that the framework created by the authors could be used as a decision support system by energy traders. The goal of this paper was to create a decision support system and the agent in our thesis is not made to support decisions and our approach is also not focused on the wholesale market.

Weidlich and Veit described several papers from the field of Agent-Based Economics that investigate the electrical wholesale markets [21]. These papers used model-based adaption algorithms, genetic algorithms, reinforcement learning, learning classifier systems, supply function optimizing agents and large scale national agent based electricity simulations, among others. These papers had different research goals, such as testing the reliability of the market or the examination of bidding strategies. The survey by Weidlich and Veit also identified several problems in the research methodology that could be improved. Examples of these issues include the argumentation of the choice of the specific learning algorithms that were used, the detailed validation and verification procedure and the detailed documentation of the simulation model. These papers were mainly orientated around the wholesale market, so a simulation of the tariff market is missing, which indicates that we can make a contribution by analyzing this area of the energy market. By analyzing the tariff market our thesis also has different goals than the papers discussed in this survey, because our goal is to improve strategies for managing tariffs and we do not use the wholesale market. In our thesis we also try to have a good explanation of our approach and we try to make the description of our simulation model as detailed as possible.

2.2 TAC Games

In many years the Trading Agent Competition (TAC) has organized several games in which agents could compete against each other. Our agent should have a strategy that could perform well in Power TAC. Since Power TAC is a TAC game it is helpful to review the previous games, because this could give us a small impression of the game setting of Power TAC and the strategies that agents might have.

Greenwald has reviewed several strategies of agents that competed in the 2002 trading agent competition [7]. This agent competition consisted of agents that acted as travel agents for their 8 clients. The foundation of the agent's architectures was founded in 2000 and some agents extended this with sophisticated AI techniques, but the best performing agents employed domain-specific heuristics. Since our approach uses domain-specific methods, we believe that it can perform well in a Power TAC competition.

Wellman et al. have analyzed the price prediction mechanisms of agents in TAC 2002 [22]. The authors focused on predicting the initial prices. They showed that instance-specific information can have advantages. They also showed that deriving the shape of a market from an idealized economic theory can be surprisingly effective. Our approach does not use idealized economic theories, but it does use some specific information of the energy market, which should give our agent an advantage.

Ketter et al. have described a prediction system for TAC SCM[12]. This system uses economic regimes. An economic regime is an observable market condition of a microeconomic situation of the market, which might be over-supply or scarcity, for example. The authors created a method to identify these regimes from historical data using Gaussian mixture models that construct price density functions. A market condition is forecasted with both an exponential smoother and with a Markov correction-prediction process. The exponential smoother was more accurate for the current and next day (supporting tactical decisions), while the Markov correction-prediction-process was better for long term predictions (supporting strategic decisions). This approach does not assume a fixed functional relationship between dependent and independent variables and is thus more flexible than other regression-based approaches. This approach is thus an example of an approach that tries to identify market conditions. Our approach does not identify specific market conditions, but it does identify different customer types and the system is adapted to the specific needs of the tariff market.

2.3 Tariffs

In the literature several types of tariffs for energy markets exist. Most tariffs are aimed at the energy consumption tariffs. In this part, a few are discussed.

2.3.1 Components of tariffs

In general most tariff have two main costs components: the electricity commodity and a risk premium paid to protect customers against price variations [9]. The way on which these costs components are structured into tariffs depends on the type of tariffs.

2.3.2 Time-independent tariffs

At first two simple tariffs are discussed. These tariffs have rates that do not depend on the time of usage. The first tariff we discuss is a flat tariff. A flat tariff is the most simple tariff. In a flat tariff, customers pay a fixed price per KWh [5]. A flat tariff has high risk premiums and it clearly favors customers that have a high consumption during peak-hours [5], since these customers won't have to pay an extra fee during these hours with energy scarcity, which means that brokers have to buy their energy at high spot prices at the wholesale market. Another time-independent tariff is the increasing block tariff [3]. In this tariff, customers pay a fixed price until a certain consumption threshold is reached after which the customers have to pay a higher rate. There might be multiple thresholds in the tariff, which means that the consumption rates might increase several times. The risk premium of this tariff is thus associated with the amount of energy consumed by customers, which means that when consumers consume more, they have to pay more for the risk of having higher prices and this risk is higher when most consumers consume more.

2.3.3 Time dependent tariffs

There are several types of tariffs that depend on time. In this section we focus on tariffs that depend on time, but are not adjusted in real time. The first tariff we discuss is the Time-of-Use Tariff [14, 20]. In a time-of-use tariff, the customer pays a higher rate during the peak hours of a day and lower prices during off-peak hours. This should give consumers an incentive to consume more during off-peak hours, which could reduce the consumption at the peak-hours. By having higher rates during peak-hours, part of the risk is transferred to the customers and thus the risk premium should be lower, although the rates may stay constant for a long time, which means that there is still an important risk premium. Consumers that have a higher demand during off-peak hours or consumers that can easily switch their consumption to other times are likely to benefit from using Time-of-Use tariffs [14]. Using Time-of-Use tariffs instead of flat tariffs can increase the total surplus of customers [20]. Since its introduction, Time-Of-Use tariffs have become a common tariff in the United States [6].

The earlier discussed flat tariffs and Time-of-Use tariffs can be combined with Critical Peak Pricing. In Critical Peak Pricing customers are charged an extremely high price under certain predetermined conditions. This might for example occur during unusual high or low temperatures. Several variations of this tariff exist, differing in variability in prices and periods [4]. The risk of price changes during these unusual events is thus transferred to the customers by having this type of tariff.

2.3.4 Real-time pricing

A Real-time pricing tariff is a tariff in which customers are charged on a half-hourly or hourly basis at a rate that may vary each day. The prices in this tariff can either be determined 24 hours in advance or earlier [1]. Consumers can thus easily be priced according to the total energy consumption during each part of the day (when the consumption is high, the prices might be higher to incentivize using less energy). By many economists, real time pricing tariffs are considered to be the most direct and efficient approach in reducing peak demands by using price incentives [2]. In real-time pricing many risks are transferred to the customer, since price changes on the wholesale market can be predicted easier on a short term and therefore the prices in real-time pricing tariffs are closer to the prices on the wholesale market. The risk premium should thus be lower than the risk premium for flat tariffs or Time-of-Use tariffs.

The first real-time pricing tariffs were introduced in the mid-1980's in California. These tariffs charged consumers with an hourly varying price, which was determined a day in advance. In 1988, a new real-time pricing tariff design was created, the two-part rate. In this tariff, customers are charged with an hourly standard rate based upon a consumer baseline load. This load is based on their historical energy consumption. On top of this baseline, the customers are charged with an hourly rate depending on their deviations from this baseline. Because only marginal changes were subject to these extra rates, prices were less volatile compared to traditional Real-time pricing tariffs. In the late 1990's Real-time pricing tariffs with separate rates for energy usage and distribution & transmission were introduced. By unbundling these components, utilities could achieve a more stable revenue [1].

2.3.5 Green tariffs

Green tariffs are tariffs in which the energy traded is produced in an environmentally friendly way. Because green energy usually has higher generation costs than non-green energy, consumers have to pay an extra premium. Green Tariffs have become popular in Germany, the Netherlands and the USA and the number of companies offering green tariffs is increasing at a fast rate [8].

2.3.6 Tariffs in the smart grid

Stavrogiannis has conducted a study in which a tariff market for households was simulated [15]. In this tariff market, the bills of several tariffs were compared. This bills were created in a simulation that was based on real data about the consumption of energy of households. He found that the cheapest bills were achieved with real-time pricing tariffs. A lack of the performed simulation was that psychological influences of customers were not properly investigated. The risk preferences and the inertia of customers was not taken into account for example. In our thesis we do take several psychological elements (such as the inertia) into account, but we do not use real data. Our thesis is more focused on time-of-use tariffs, the identification of different customer types, and pricing tariffs more competitively than competitors and we do not focus on different types of tariffs.

2.4 Tariffs in competitive electricity markets

2.4.1 Tariffs in competitive electricity supply markets

Keppo and Räsänen created a model to price tariffs in competitive electricity supply markets [11]. Their model uses the value of the customer's electricity consumption pattern. Their model is based on the future price of the value of this pattern. Their model showed that customers with a high uncertainty in their consumption pattern should be charged more than less uncertain customers. Their analysis also indicated that deterministic load profiles cannot be applied in a competitive market, because they do not include the consumption risks. In this paper, the focus is on creating a specific pricing model for a customer's consumption pattern, but in our thesis, the focus is on creating a strategy that can alter tariffs to attract customers that are subscribed to competitors. We also use a simulation and not a mathematical model as our approach and therefore the goal and the approach of our thesis is different than the approach and the goal of this paper.

2.4.2 Tariffs that are being adapted in a competitive electricity market

Reddy and Veloso used a simulation approach to investigate a competitive tariff market [18]. The tariff market that they simulated was heavily simplified, because tariffs could only have one rate and therefore different types of tariffs could not be used. The daily effects of a day were also ignored in this paper, because the consumer's consumption was a fixed parameter that remained the same throughout the entire simulation. This also meant that modeling different customer types was not possible. The customer model was able to rank and pick tariffs according to the customer's preferences, which consisted of the tariff prices and the inertia of the customer. The paper used agents with fixed, random, balanced, greedy and learning strategies. Each tactic used different actions for altering the tariff rates. The learning strategy learned an Markov Decision Process policy by using Q-learning. The states in the Q-learning algorithm consisted of two elements. In the first element the rationality of the tariff market is determined by using a heuristic that determines whether the tariff market is rational, which is the case if the lowest price of all consumption tariffs is higher than the price that is an increase of the highest price of all production tariffs by a certain margin. The second element of the states consisted of a part that determined whether more energy was sold than bought or vice-versa, or that the amount of energy that was sold and bought was balanced. The actions taken in the Q-learning algorithm included: maintaining the same rate, lowering or raising the rate by a fixed amount, increasing or decreasing the rates to the midpoint of all tariff rates (including the competitor's tariff rates), copying the maximum and minimum tariff rates, and changing the rate to slightly below or above the midpoint of all tariff rates. The paper demonstrated that the agents that used the learning strategy won most games in terms of overall profit by demonstrating this in several figures. The authors did however not use a t-test. This thesis has many similarities with this paper, since this paper is also about tariffs. A major difference is that customers in this thesis are more complex and daily patterns are more realistic. More types of tariffs are included in this thesis as well. Our agent has more specific algorithms to improve its tariffs. A disadvantage of Q-learning is that it is difficult to take every circumstance into account, because this would have to be represented in states and these states might increase at a huge rate if many circumstances are included in them. The goals of this thesis are similar to the goals of this paper, since both papers attempt to model a broker that attempts to make a profit by creating electricity tariffs. The main difference is the approach and the complexity. This thesis uses a more specific approach and the simulation environment is also more complex than the environment used in the paper of Reddy and Veloso.

2.5 Conclusion

Currently most literature with regards to agent-based energy markets is focused on the wholesale market. Most literature with regard to tariffs is mainly focused on the success of different types of tariffs (flat tariffs, Time-of-Use tariffs, Real-time Pricing). Most tariffs that are discussed in the literature are consumption tariffs and the prices of these tariffs are related to the prices of energy on the wholesale market. Tariffs can differ in risk, depending on how much their prices change. For this risk, a premium has to be paid. A common question in the literature is thus how much risks the consumers or utilities are willing to take. There is however few literature about designing tariffs in a competitive setting. In today's liberalized energy markets, many energy brokers can offer tariffs and compete with each other. It is thus interesting to investigate successful strategies in offering these tariffs. Power TAC offers a framework in which this is possible. By investigating tariffs in this new setting, we can learn more about the structure of competitive energy markets in the future.

Chapter 3

Power TAC

3.1 The Power TAC environment

3.1.1 Introduction

Power TAC is a competition in which agents compete with each other in the energy market. The competing teams are 'brokers' that aggregate energy demand and supply with the intend of earning a profit. Brokers buy and sell energy through tariffs with retail customers and by trading energy on the wholesale market. In Power TAC brokers can also negotiate contracts with big customers, but this feature is not included in the Pilot Competition and the first official competition in 2012. Brokers can however offer tariffs to a population of anonymous small customers and energy can be bought or sold at the wholesale market. A broker has to be perfectly balanced at the end of each timeslot or otherwise it will receive a penalty from the distribution utility. This penalty depends on the size of the imbalance of the broker, the imbalances of other brokers, the market prices of energy, and the amount of controllable loads, among others. Our thesis focuses on creating tariffs and therefore we shall focus on explaining this part of the Power TAC environment. A detailed description of Power TAC can be found in the game specification [13].

3.1.2 The customer models and the tariff market

The consumption patterns of the customers in Power TAC are based on three classes: households, offices and factories. An implementation of electric vehicles is also planned for the Power TAC Competition, but this class was not available in December 2011. Households have a typical residential consumption behavior. They consume more in the early morning, late afternoon and evening. Sharp peaks might happen in the early morning or in the late afternoon or early evening. Offices have a typical flat consumption during office hours and a limited consumption at other times. The patterns of factories or similar to those of offices, but the factories have greater magnitudes and more variance.

The customer's decision model is based upon several factors that can be prioritized by attaching weights to them. The involved factors are the variable and fixed costs, the energy content (the amount of renewable energy), the risks (of price changes in dynamic tariffs), and inertia. Based on these factors a utility is calculated and this utility is used in a logit choice model that picks the tariff. We use the same logit choice model in our Simulation Framework and more details about this model can be found in the chapter about this framework.

The tariff structure of Power TAC is described in Figure 3.1. In this Figure, the classes in yellow, *TariffSpecification*, *Rates* and *HourlyCharges*, are classes that can be defined by the broker and the broker sends these classes to the server. The classes in red, *Tariff* and *TariffSubscription* are only used in the server. A tariff that arrives at the server is wrapped with the class Tariff and the rates are remapped in a 2D array, indexed by tier and hour. By using the classes provided by Power TAC it is possible to model several tariffs (flat tariffs, time-of-use tariffs, tariffs with weekday/weekend rates, two-part tariffs, tariffs with signup payments or early withdrawal penalties, tariffs with variable rates with minimum and maximum values). In the Pilot Competition many type of tariffs were not available and therefore mainly flat tariffs and time-of-use tariffs were used. These types of tariffs are also the focus of this Thesis. Researching other types of tariffs in combination with my framework is an interesting topic for future research.

A broker can send a tariff to the server at any time. This tariff is offered periodically

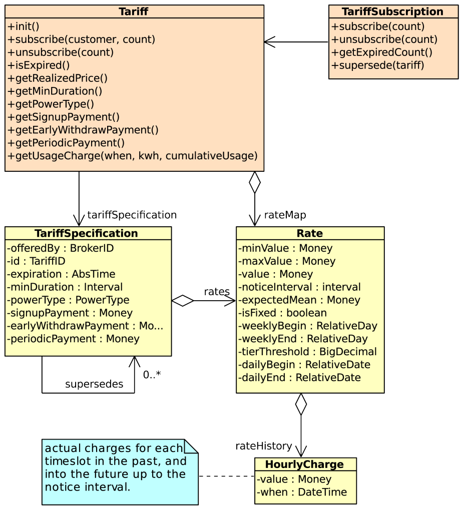

Figure 3.1: Tariff Structure

to the market at which time the customers can subscribe to the tariff. Tariffs can also be changed. To do this, a tariff has to be revoked. This means that the old tariff is removed from the server and customers can no longer subscribe to it. It is however possible for brokers to keep their old customers. This can be done by creating a tariff that supersedes the old tariff. By doing this the contract duration of the customers of the old tariff has a value of 0, but these customers will be subscribed to the new tariff. Tariffs can also be expired if they have an expiration date. The tariffs that are offered to customers are public, which means that every Agent can see them. Details about the transactions of the tariffs are however only send to the agents that published these tariffs.

3.2 The pilot competition

3.2.1 Introduction

The pilot competition was held at the 17th and 19th of July 2011. The goal of this pilot competition was to get a first impression of future competitions. Due to several development issues, the pilot competition was far from perfect. These issues are discussed in this section. We focus on the tariff market, the most relevant part for our thesis.

3.2.2 Tariff Market

The tariff market consists of brokers that offer tariffs and customers that might subscribe to these tariffs. An initial look at the data already indicates that imbalances are unavoidable. The total produced energy varied between approximately 3000 and 7000 MW, while the total consumed energy varied from 50.000 to 70.000 MW. Imbalances are thus almost impossible to avoid. Besides that, the rates of production tariffs were often higher than the rates of consumption tariffs. This resulted in an unprofitable situation, because brokers would purchase energy at a higher rate than they would sell it. Some customer became reasonably sticky to a certain tariff after a few days, which made a good performance in the first part of the game crucial. This stickiness indicates that inertia plays an important role in the customers' decision model. In Figure 3.2 the total transactions per broker for the consumption tariffs can be seen. This can give an indication of the performance of each broker.

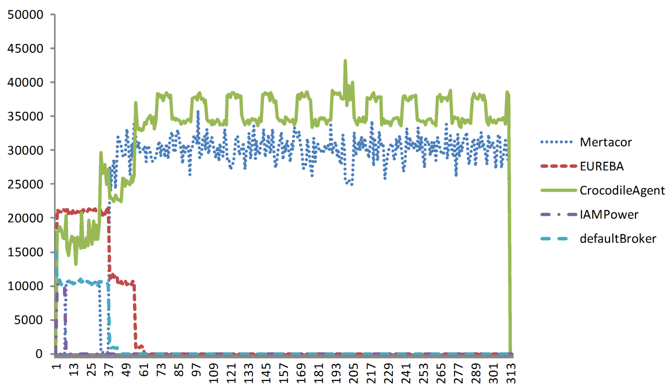

Figure 3.2: Total transaction per broker of consumption tariffs

An interesting observation is the success of expensive tariffs in the beginning. IAMPower offers the most expensive tariffs (a constant rate of 8, while the rate of the defaultBroker is 0.75) and surprisingly IAMPower still manages to attract customers in the first set of timeslots. EUREBA also has rates that are higher than the competitors, but this does not seem to influence their performance in the first timeslots. After a while Mertacor and the CrocodileAgent seem to attract most consumers. This is logical, because they have the lowest rates. An interesting observation is that the cheapest consumption rates of Mertacor are lower than the rates of their production tariffs, which means that they buy energy at a higher price than they sell it and therefore they could lose money, even if they have a balanced portfolio.

In Figure 3.3 a graph displaying the total transactions of production tariffs per broker can be seen.

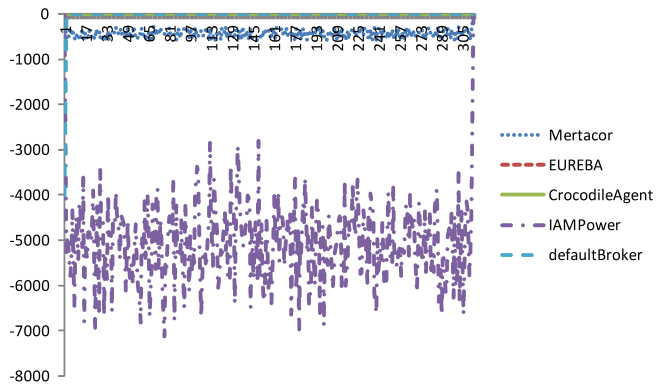

Figure 3.3: Total transaction per broker of production tariffs

It can be clearly seen that IAMPower attracts most of the producing customers. This is due their high rates (a rate of -8 compared to a rate of -0.01 for the defaultBroker). Mertacor manages to get a small share of the producers, while it has a rate that is much lower than IAMPower (-0.12). Mertacor and IAMPower were the only brokers, besides the defaultBroker, that had negative rates and therefore they were the only brokers that could attract producers, which it makes it no surprise that all producers were subscribed to either IAMPower or Mertacor. It is however surprising that Mertacor manages to attract some producers, because the tariffs of IAMPower are much more attractive.

3.2.3 Other components

The imbalances that exist as a consequence of the actions in the tariff market have to be resolved in the wholesale market and in the real time market (by the distribution utility). Based on the customer portfolio, the imbalances of each timeslot have to be predicted. This has proven to be difficult, since many customer models did not perform well. Only the customer models of village1 and village2, seem to have some daily patterns. The other customer models seem to have random patterns each day. More about the patterns of the customer models can be found in section 3.3, which discusses the problems with the bootstrap data of the server that was created in December. These problems are similar to the problems with the customer models of the server of the Pilot Competition. The thesis of Kevin Meijer also gives a good explanation of the problems with the customer models. The random patterns created by the customer models are difficult to predict. A result of this is that predictions are unreliable and therefore many imbalances exist and the distribution utility has to solve these imbalances by balancing the market. In Figure 3.4 the total imbalances of all agents are depicted.

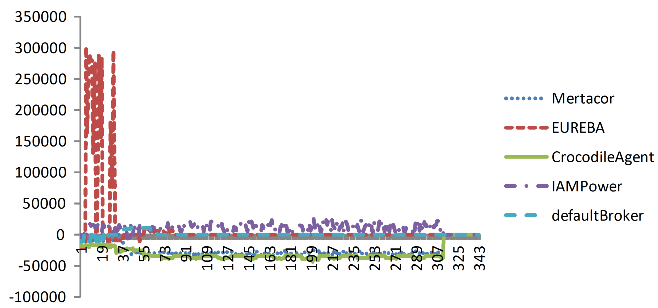

Figure 3.4: Total imbalances of agents

The most obvious observation is the huge imbalance that EUREBA has in the beginning stages of the game. This is probably caused by wrong predictions that are probably based on wrong bootstrap data, because after a few timeslots the imbalances are less big. The other agents are also imbalanced. IAMPower seems to keep the imbalances they made in the tariff market, which can also be said of Mertacor and the CrocodileAgent.

Therefore it can easily be concluded that no broker managed to balance their energy imbalances sufficiently on the wholesale market. In Figure 3.5 the imbalance charges are depicted.

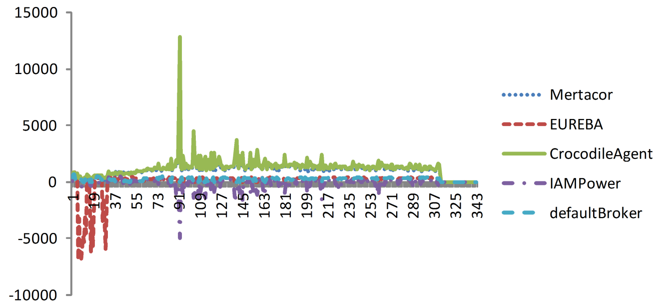

Figure 3.5: Total charges of agents

A noticeable observation is that EUREBA has high charges in the beginning of the game, which is something that is probably caused by the wrong predictions they made due to the incorrect bootstrap data and random patterns of the customers. Besides this, it is strange that there were suddenly high charges for both the CrocodileAgent and IAMPower at timeslot 92. The imbalances at this timeslot were similar to previous timeslots, so it is difficult to explain these imbalances. It is also noticeable that most charges for IAMPower were negative, which means that they received money. This is probably caused by the fact that they were the only agent that had a positive imbalance (they bought more energy than they sold).

Another important part of the pilot competition is the wholesale market, but this market is not the focus of this thesis and therefore it was not extensively analyzed, although we have analyzed it a bit. The most successful broker on the wholesale market is without a doubt IAMPower. IAMPower seems to make a lot of profit on the wholesale market. They seem to buy a lot of energy at a low price and sell it at a higher price. This seems to cause their high cash flows. Due to the focus of our thesis, we have not analyzed their strategy extensively, since this would require too much time.

3.3 Analysis of the bootstrap data of the Power TAC server of December

3.3.1 Introduction

In December a new version of the Power TAC Server was released. We have analyzed this server. It was not possible to connect a broker to this server at the time of the release and even if this was possible, it would have cost extra time and we needed to know the performance of the server quick, so therefore we only analyzed the bootstrap. Only the data about net usages was used in this analysis. The data consisted of 14 days of net usages by the different customer types. We have taken the average of each hour for 2 weeks and we have used this to compute an average day. The results are explained in the next subsections.

3.3.2 Overall

Figure 3.6 depicts the average net usage per hour of a day of all customers. Consumers have a negative load and producers have a positive load. Since it is difficult to see the details of consumers with a small load, we focus on HighlandBusinesses and MoreWood-households in this section. HighLandBusiness, an office, has a net load that rarely varies and that does not change during the day. HighlandBusinesses is however an office, so the load should be higher during office hours (between 09:00 and 17:00). MorewoodHouseholds has a higher variance, but the pattern seems to be random. MorewoodHouseholds is a household and should thus consume more around 07:00-09:00 and 17:00-23:00. This is clearly not the case.

3.3.3 Producers

Figure 3.7 depicts the average net usage per hour of a day of the producers and Household 1 and 2. The producers can either be an office or a factory. WindmillCoOp is a factory and UniFacilities & JennywoodPark are offices. The description of these classes in the Power TAC specification clearly does not match with the patterns of the customers in

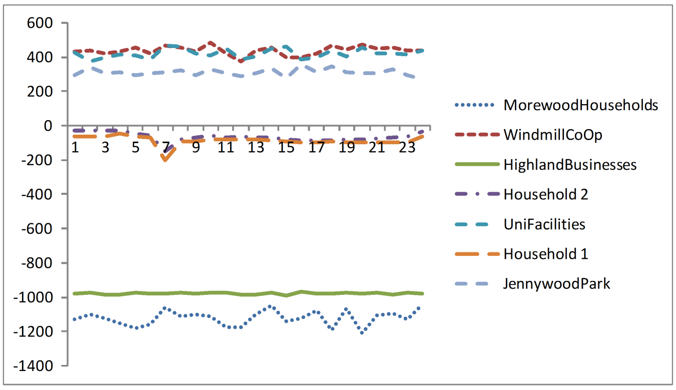

Figure 3.6: Average net usage of all customers

this server, because WindmillCoOp does not have higher and more variable loads, which it should have, since it is a factory. The patterns also seems to be random.

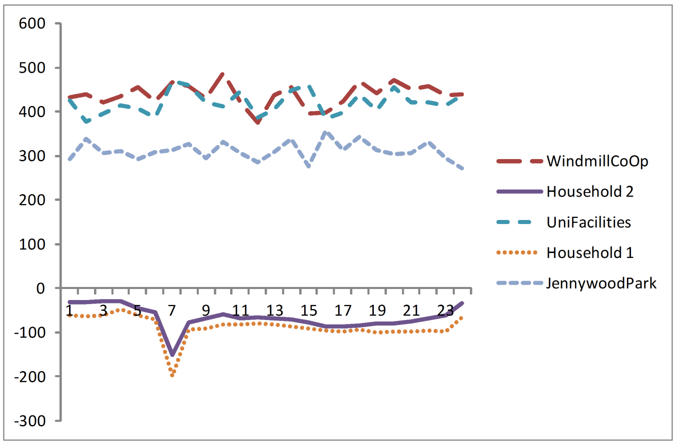

Figure 3.7: Average net usage of the producers and Household 1 & 2

3.3.4 Household 1 & 2

In Figure 3.8 the average net usage per hour of a day of Household 1 & 2 are depicted. The patters seems to make sense. In the morning there is a high peak, which is probably the moment at which people wake up. The consumption is relatively low during office hours and it increases slightly near the end of the office hours. There is however no peak at the end of the day. The consumption during the night seems to be low, which is also something that we could have expected.

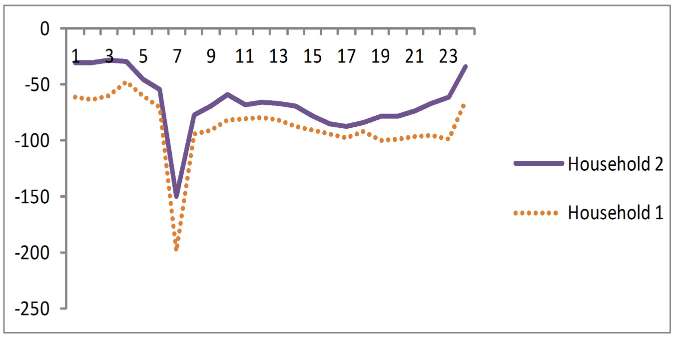

Figure 3.8: Average net usage of Household 1 & 2

3.4 Consequences of the server performance for our work

The analysis of the Pilot Competition clearly shows that the performance of the server of this competition was not functioning well. The customer models were random and difficult to predict and there were also some problems with the balancing market. The bootstrap data of the server that was created in December also had a bad performance. Simulating an agent in an environment that is not functioning properly is not a good idea. Therefore we have created a new simulation environment for our agent. This environment is a strong simplification of Power TAC that focuses on the tariff market. It includes the most important aspects that we need to simulate our agent and therefore this environment gives us the chance to test our agent in a stable and reliable environment that is specifically made to simulate the tariff market. It also allows us to change the variables in the customer models and therefore we have the opportunity to test our agent in simulation environments with different settings. We do however use some data structures used in Power TAC in designing our tariffs. The tariffs that we create use the class TariffSpecification of the Power TAC server. By using these data structures it should be easier to convert our agent to an agent that could work in Power TAC.

Chapter 4

Simulation Framework

4.1 Introduction

In this chapter the Simulation Framework is described. This is the environment in which the agents perform their actions. Section 4.2 discusses the tariffs. Section 4.3 discusses the default broker. Section 4.4 discusses the customer preference models, while section 4.5 describes the customer net usages and the last section, section 4.6, describes the balancing mechanism. Our simulation framework follows a fixed set of steps. First the customers select their preferred tariffs. After this the customers consume or produce energy. When the customers have performed their actions, the distribution utility balances the market. Finally, the agents perform their actions, which means that they can alter their portfolio of tariffs. Currently the number of steps is executed on every timeslot in first 24 timeslots and every day after that. By executing the number of steps more in the beginning of the game, we can stabilize the market and reduce effects that take place at the beginning of the game.

4.2 Tariffs

The tariffs used in our simulation environment have the same structure as the tariffs used in the Power TAC server. Each agent has to define its tariff by using the TariffSpecification class of the Power TAC server. Only flat rates and time-of-use tariffs are supported, because our agent framework currently does not offer any other type of tariffs. Tariffs can be send to the Simulation Environment at any time and they are published in the next timeslot. For the current timeslot, the old tariffs are available to the customers. The customers will however only pick tariffs on certain timeslots. These timeslots are every timeslot in the first 24 timeslots and one timeslot every day (every 24 timeslots) after that. This is related to the timeslots at which the simulation environment performs its fixed set of steps, which is described in the introduction of this chapter. Tariffs can be revoked and it is possible to keep the customers of the old tariff by letting a new tariff supersede the old tariff. The tariffs that are offered to customers are public, which means that every agent can see them. Details about the transactions of the tariffs are however only send to the agents that published these tariffs.

4.3 Default broker

In the beginning of the game, all customers are subscribed to the default broker, which is an agent with unattractive tariffs (a production tariff with a flat rate of -0.05 and a consumption tariff with a flat rate of 1.99). The tariffs published by other brokers are usually better and therefore most customers should switch to another tariff quickly. The default broker is designed to reduce begin-game effects and it is based on the default broker used in Power TAC.

4.4 Customer preference model

4.4.1 Customer utility

The customer preference model is based on the specification of Power TAC. It is however a simplified version of it, since not all aspects are needed the test the performance of our agent. The choice of a tariff depends on the utility of a tariff. The utility for a tariff i is determined as follows:

$$u_i = -\frac{c_v(i)}{\max_{i \in C} c_v(i)} \alpha_{costs} + I(i)\alpha_{intertia} \quad (4.1)$$

The elements energy and risk, that are included in Power TAC, are not included in this framework. The reason is simple. Our framework does not make use of green energy and it also does not make use of dynamic tariffs (so there is no risk factor of a dynamic tariff). The fixed costs are ignored as well, because fixed costs our agent do no publish tariffs with fixed costs. Having no fixed costs also makes the customers more flexible, which allows us to study a more dynamic market. The alphas are weights used to simulate the customer's preference for certain aspects of a tariff. By changing these alphas we can thus make customers emphasize the Inertia or the costs of the tariff.

The element $c_v(i)$ consists of the variable costs of tariff i. At first the optimal consumption under this tariff for k random days is determined. Consequently the costs $c_v^*(k)$ for a day are calculated and the results are averaged: $c_v = \frac{\sum_k c_v^*(k)}{k}$. When less than k days are available, all days are used. In the first 24 timeslots, data from a full day is unavailable. Therefore we use a fixed pre-determined pattern of consumption for the first timeslots. These patterns are replaced by real data when this data is available. For example, when the simulation is at timeslot 5 and the customers have consumed their energy, than the consumption of energy at timeslot 5 replaces the value of the fixed pre-determined pattern. The customers will thus use a day with real data in the first 5 timeslots and fixed-predetermined data for the 19 remaining timeslots of that day. We normalize the costs on every day to make the comparisons between tariffs more reliable. The variable costs are normalized by dividing the variable costs of each day through the maximum variable costs of the tariffs that are available in set C. Set C contains all tariffs, except the tariff with the highest variable costs. The highest variable costs are thus not used to normalize the costs. By doing this, we increase the differences in utilities between the tariffs and therefore it should be easier for customer to distinguish different tariffs from each other.

The element $I(i)$ stands for the inertia of tariff i. The inertia reflects the behavioral preference to stay with the current tariff. The value of $I(i)$ is 1 if the tariff to which the customer is currently assigned to is i and 0 otherwise.

4.4.2 Choosing a tariff

For choosing a tariff from a list of tariffs we use the logit choice model that is described in the specification of the Power TAC Server. So the probability of picking tariff i from the set of tariffs $\mathbb{T}$ is:

$$\mathbb{P}_i = \frac{e^{\lambda u_i}}{\sum_{t \in \mathbb{T}} e^{\lambda u_t}}, where : \lambda \geq 0 \tag{4.2}$$

The parameter λ is used to measure the rationality of a customer. When $\lambda = 0$, the customer picks a new tariff randomly, while the tariff with the highest utility is chosen when $\lambda = \infty$. A higher λ thus results in choices that are more rational. Each customer can have the same λ or a different λ. By giving a different λ to different customers, we can simulate a heterogeneous market. If we do this, we should create relationships between the rationalities and the types, because this is more realistic. We can for example give profit-maximizing Offices or Factories a higher λ than Households, because Offices and Factories are probably more motivated to lower their costs, which requires decisions that are more rational.

The rationality of the customers also depends on the amount of tariffs that are published and the differences between these tariffs. We can illustrate this with an example. Suppose that we have two flat tariffs and one customer (a producer) that is not assigned to any tariff and the customer is not inert. This customer has a production of 1 kWh at each day . One tariff has a rate of 0.39 and the other tariff has a rate of 0.40. The probability of picking the best tariff per λ in this case is depicted in Figure 4.1.

Now suppose that we have the same customer and that this customer can now pick between 20 flat tariffs. One tariff has a rate of 0.40, while the others have a rate of 0.39. The probability of picking the best tariff per λ for this case is depicted in Figure 4.2.

It can be clearly seen that for 20 tariffs a higher λ is needed to have the same

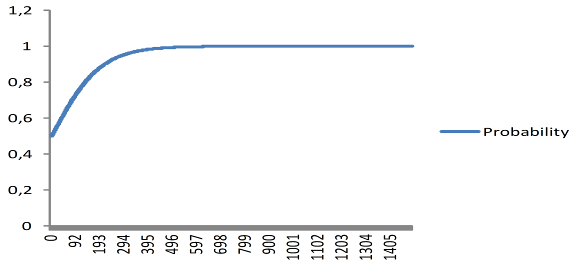

Figure 4.1: Probability of picking the best tariff per λ out of 2 tariffs

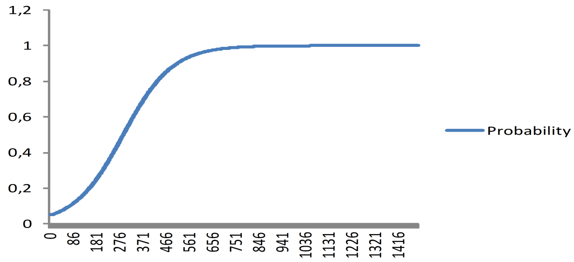

Figure 4.2: Probability of picking the best tariff per λ out of 20 tariffs

probability of picking the best tariff. The relationships between the amount of the tariffs and these probabilities should be taken into account when λ's are assigned to customers. Besides the amount of tariffs, the differences between tariff rates should be taken into account too. To illustrate this, we can use the same example with the same customer and the same amount of tariffs, but now all tariffs, except the best tariff, have a rate of 0.36. The probabilities of picking the best tariff for this illustration can be seen in Figure 4.3.

Figure 4.3 clearly shows that a bigger difference between the rates of the tariffs results in higher probabilities of picking the best tariff. Therefore it is also important to analyze this aspect when λ's are assigned to a customers.

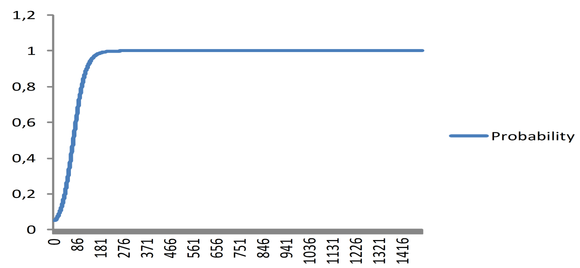

Figure 4.3: Probability of picking the best tariff per λ out of 20 tariffs with a noticable difference in tariff rates

4.5 Customer net usages

The customer net usages in this thesis are based on energy usage models created by Kevin Meijer. More information about these models can be found in his thesis.

We generate the energy usage value v_t^c of customer c for timeslot t as:

$$v_t^c = p_{t \in h}^c \cdot b^c, \text{ where:} \tag{4.3}$$

$$p_{t \in h}^c = g_h^c \cdot (1 + r_t^c), \text{ and:} \tag{4.4}$$

$$r_{t \in h}^c = \alpha \cdot random(d_c) + (1 - \alpha) \cdot r_{t-1}^c, \text{ and:} \tag{4.5}$$

$$r_{-1}^c = 0 \tag{4.6}$$

where d_c is the deviation percentage of customer c, $random(d_c)$ is defined as a randomly selected proportion within the interval $[-\frac{d_c}{100}, \frac{d_c}{100}]$, g_h^c is a base proportion belonging to customer c for hour h, $r_{t \in h}^c$ is the relative increase over base proportion g_h^c at timeslot t, $p_{t \in h}^c$ is the computed proportion for customer c at timeslot t, b^c is the base value of customer c and v_t^c is the generated consumption or production in kWh of customer c at timeslot t. α is used to determine the influence that either the randomly generated proportion $random(d_c)$ or the proportion from the previous timeslot r_{t-1}^c has on the generated proportion $p_{t \in h}^c$. α has an interval of $[0, 1]$. In our setting, we set α to 0.3.

The base proportions g_h^c for different customer types and different timeslots can be seen in Table 4.1

Table 4.1: Base proportions g_h^c for all customer types and hours

Hour	Household	Office	Factory
0	0,42	0,37	0,15
1	0,41	0,37	0,15
2	0,4	0,38	0,16
3	0,43	0,39	0,18
4	0,52	0,42	0,22
5	0,6	0,47	0,28
6	0,65	0,61	0,47
7	0,67	0,74	0,65
8	0,65	0,84	0,78
9	0,65	0,89	0,85
10	0,62	0,95	0,93
11	0,62	0,96	0,95
12	0,62	0,97	0,96
13	0,62	1	1
14	0,64	1	1
15	0,67	0,95	0,93
16	0,75	0,89	0,85
17	0,81	0,79	0,72
18	0,97	0,66	0,54
19	1	0,54	0,38
20	0,95	0,49	0,31
21	0,85	0,47	0,28
22	0,76	0,42	0,22
23	0,57	0,39	0,18

This Table clearly shows the net usages per customer. A higher proportion indicates a higher consumption or production. Offices and Factories have a higher consumption during office hours (9-16), while households have a higher consumption in the late afternoon and evening (17-22) and their consumption in the early morning (6-7) is higher than their consumption in the late morning and early afternoon (8-14). The consumption during off-peak hours is also lower than during peak-hours, which is also a realistic assumption. These types thus have a consumption that is similar to the consumption that is described in the Power TAC specification.

Besides the proportions, we use fixed pre-determined energy usages in the first timeslots. This was described in section 4.4.1. A Table with these values can be found in

Table 4.2.

Table 4.2: Pre-determined energy usages per customer type

Timeslot	Household	Office	Factory
0	320	255	450
1	310	250	410
2	280	250	380
3	290	210	390
4	350	270	450
5	540	280	640
6	620	420	620
7	1490	520	790
8	770	670	770
9	680	880	780
10	590	790	790
11	670	770	770
12	650	850	750
13	670	870	770
14	670	880	780
15	670,5	790,5	790,5
16	700,5	750,5	750,5
17	780,5	650,5	780,5
18	1020,5	550,5	790,5
19	780	320,5	760,5
20	780,5	320,5	750,5
21	740,5	310,5	740,5
22	730,5	280,5	730,5
23	590,2	260,2	590,2

Table 4.2 has energy usages that represent the description in the specification of Power TAC too. Offices and Factories have a higher consumption during office-hours, while households have a higher consumption in the late afternoon, the evening and early morning.

4.6 Solving imbalances

Imbalances are solved by our Distribution Utility. Our Distribution Utility has a simple way to solve imbalances. The costs of an imbalance only depend on the size of the imbalance and the type of imbalance. We have defined the costs of an imbalance by broker j as:

$$BC_j = c_1 \cdot (|(e_c(j) - e_g(j))|), \text{ if } (|e_c(j) - e_g(j)|) \leq ra \text{ or } e_g(j) \geq e_c(j) \tag{4.7}$$

$$BC_j = c_1 \cdot ra + c_0 \cdot ((|(e_c(j) - e_g(j))|) - ra), \text{ if } (|e_c(j) - e_g(j)|) > ra \tag{4.8}$$

$$c_1 = 0.2 \cdot c_0, j \in C, a = e_c(j) + e_g(j), r \in [0, 1] \tag{4.9}$$

In which c_1 and c_0 are the balancing costs per kWh, $e_c(j)$ is the amount of consumed energy for broker j, and $e_g(j)$ is the amount of produced energy for broker j. a is the total amount of energy that is produced and consumed and r is a ratio of the total amount of energy. We set r to 0.2. The broker only pays the amount c_1 if the energy imbalance is less than the ratio r of the total amount of energy a. Imbalances are inevitable and therefore small imbalances have lower balancing costs per kWh. c_1 is also paid when more energy is produced than consumed, since it is probably easier to solve these imbalances on the wholesale market and these costs should reflect that. c_0 is paid for the amount of energy that is higher than the ratio r of the total amount of energy a. c_1 is based upon the costs c_0, which can be set by the user.

A disadvantage of this method compared to Power TAC is that this method is unable to take the full market situation into account. In Power TAC a broker with a surplus of energy could even get a bit of money for his energy if it is the only broker with a surplus. This is not the case with this method. An advantage of this method is that it is simple and it allows us to focus on the tariff market.

Chapter 5

Agent Framework

5.1 Introduction

In this chapter the framework of the agents of my thesis is described. This framework is a tariff adjustment system that adjusts tariffs according to their performance and it also analyzes the tariffs of competing tariffs. In Figure 5.1, the basic framework is depicted. First the initial tariffs are offered as described in section 5.3. These tariffs are classified according to the types described in section 5.2. Following this, the score of each tariff is calculated which is described in section 5.4. An imbalance scenario is consequently determined and based on this certain actions are taken as is described in section 5.5. Finally some tariffs are copied with a specific method described in section 5.6.

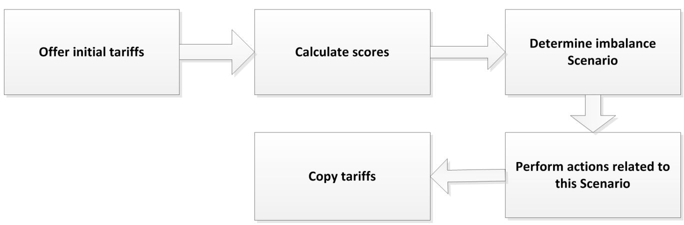

Figure 5.1: Framework

5.2 Types of Tariffs

Many types of tariffs exist. In this thesis we only focus on two types: the flat tariff and the time-of-use tariffs. Ideally we would use real-time pricing tariffs as well. However, these tariffs were not included in the pilot competition and were also not included in the Power Tac server that was available in December. Our Agent Framework is based on these servers and therefore we did not include real-time pricing tariffs to our framework.

In the customer preference model used by Power Tac, the risk factor is only associated with the differences in realized prices of real-time pricing tariffs, which means that Power Tac does not evaluate the differences in risks between time-of-use tariffs and flat rates, a difference that exists in reality. Since our simulation framework is based on the models of Power Tac, we also do not evaluate these differences in risks. The cost aspects of both tariffs are however evaluated in both Power Tac and our simulation framework. For both simulation environments, a consumer compares the average costs of consumption or production per day. We can thus use the pattern of consumption of a specific class to make a specific tariff for that class. For example, a tariff made for offices might have lower rates during office-hours and it could therefore be more attractive to offices. We can determine the class of a tariff by classifying it.

We classify tariffs by using different kind of averages, which are based on the rates of tariffs on certain hours of a day. These averages are:

- 24 hour rate average $= \frac{\sum_{t=0}^{t=23} p_t}{24}$
- office/factory peak-hour average $= \frac{\sum_{t=9}^{t=16} p_t}{8}$
- Household peak-hour average $= \frac{\sum_{t=7}^{t=8} p_t + \sum_{t=17}^{t=22} p_t}{8}$
- Peak average $= \frac{\sum_{t=7}^{t=22} p_t}{16}$

We can use these averages as features in our classification method. Our classification method consists of one classification rule and the k-nearest neighbors classification method. The only class that can be defined by a classification rule is the flat tariff. This rule is used before k-nearest neighbors is used. This classification rule is defined as:

- If all averages are the same, then the tariff can be classified as a flat tariff

A flat tariff has the same rates throughout the day, which means that all averages should be the same too. If the mentioned classification rule does not classify the tariff as a flat tariff, than k-nearest neighbors can classify it as one of the following classes:

- The office / factory tariff, which is a tariff that has rates that are most attractive to offices and factories.
- The household tariff, which has rates that are most attractive to households.
- The peak tariff, which has high rates during peak-hours, but its rates are not more attractive for a specific customer. This class is thus used to describe tariffs that are not aimed at attracting a specific customer type.

We thus have 3 classes that we need to classify using the k-nearest neighbors algorithm with a set of 4 features (which we define as $x_1, x_2, ..., x_4$). The algorithm of k-nearest neighbors can be described as follows:

1. Compute the distances between all records.
2. Find the nearest k neighbors to the record that has to be classified using the earlier computed distance.
3. Use a majority decision rule to classify the new record, where the new record is classified as a member of the majority class of its k nearest neighbors.

We can use the Euclidian distance as our distance measure. The Euclidean distance between the records $(x_1, x_2, ..., x_p)$. and $(u_1, u_2, ..., u_p)$ can be defined as:

$$D_{Euclidean}(x, u) = \sqrt{(x_1 - u_1)^2 + (x_2 - u_2)^2 + ... + (x_p - u_p)^2} \tag{5.1}$$

To train our algorithm, we use the initial set of tariffs we offer and a fixed set of tariffs that only exists in the training set. These tariffs are classified by ourselves, since we can have an idea of the type of customers that will be attracted to these classes. Tariffs with higher rates during office hours, will undoubtedly attract more factories and offices than households. We can thus create a reasonable estimate of the type of customers that will be attracted to certain tariffs. The set of tariffs that is only available in the training set consists of tariffs with a rate of 0.58 during the peak-hours of a specific class and a rate of 0.64 during the peak-hours of another class. The off-peak hours rate of these tariffs is 0.55. These tariffs are created for households and offices and the differences between the rates in the tariffs are small, which makes them useful when the prices on the tariff market are converging. In the initial tariffs that are offered to the market, a peak tariff will be published too, but more about this can be found in the next section.

New tariffs are classified using the earlier defined classification rule and k-nearest neighbors. Classifications can be altered when the attracted customers are known. This happens when the majority of attracted customers has a customer class that is different than the classified customer class. We can also classify tariffs of other brokers using this method, which is discussed in section 5.6. Producers are not classified in this way, because we want to focus on consumers. Producers also have less classes than consumers, which makes making specific tariffs more difficult.

5.3 Initial Tariffs

In the beginning of the game a set of tariffs is offered. This set of tariffs are classified by ourselves. There are 4 types of tariffs that are published: a household tariff, an office/factory tariff, a peak tariff, and a producer tariff. The production tariff is a flat tariff and the consumption tariffs all have lower rates during off-peak hours (23-5). The household and office/factory tariffs have lower rates during the peak hours of their class in comparison with the peak-hours of other class. This means that an office/factory tariff has lower rates during office hours (9-16) in comparison with the household peak hours (7-8,17-22). The opposite applies to the household tariff. The peak tariff has flat rates during peak hours (7-22). All published tariff also obey the following rule:

- On all hours, the hour-specific rate of the best performing consumption tariff must be better than the hour-specific rate of the best performing production tariff.

By obeying this rule, unprofitable situations can be prevented. We do not want to buy energy at a higher price than we sell it. The performance of the tariffs is based on scores, which are explained in the next section.

5.4 Tariff Scores

There are many tariffs that are published and active. We need a way to identify the most successful tariffs. We do this by calculating a score for each tariff. This score determines how successful a tariff is. The scores are made for one day. If the first day of the simulation has not passed, than all timeslots until the current timeslot are considered to be a day. A score of one day is computed as follows:

$$score_{t,i}(Co) = -\alpha \cdot \frac{s_{t,i}}{max_t s_{t,i}} + \beta \cdot \frac{r_{t,i}}{max_t r_{t,i}} \tag{5.2}$$

$$score_{t,i}(Pr) = -\alpha \cdot \frac{s_{t,i}}{max_t s_{t,i}} + \beta \cdot \frac{c_{t,i}}{max_t c_{t,i}} \tag{5.3}$$

$$\alpha + \beta = 1 \tag{5.4}$$

$$Co = \{H \vee O \vee Pk\} \tag{5.5}$$

$$Tr = \{H, O, Pk, Pr\} \tag{5.6}$$

In which t is a tariff and i is a day. Type H is a household tariff, type O is an office factory tariff, type Pk is a peak tariff, and type Pr is a production tariff. Tr is a collection of all tariff types and Co is a type that is a consumption tariff. The score consists of two elements: a cost/revenue based element and a variability element. The first element tries to increase profits by giving tariffs with lower costs, higher revenues and a higher quantity of produced or consumed energy a higher score. The second element tries to reduce variability. This element is represented by the standard deviation $s_{t,i}$.

We can emphasize these elements by changing the parameters α and β. The elements are normalized by dividing the elements by the maximum value of that element.

The element $c_{t,i}$ is not only based on the costs, but also on the amount of produced energy, because lower costs are also achieved when there are fewer transaction. Therefore we also take the quantity of energy into account, so we define $c_{t,i}$ as follows:

$$\begin{aligned} c_{t,i} = -a \cdot \frac{y_{t,i}}{max_t y_{t,i}} + b \cdot \frac{q_{t,i}}{max_t q_{t,i}}, y_{t,i} = \frac{p_{t,i}}{q_{t,i}}, \\ a + b = 1 \end{aligned} \tag{5.7}$$

In which $p_{t,i}$ is the average daily rate of tariff t and $y_{t,i}$ is this rate divided by the total quantity. In this equation, the part multiplied by a minimizes costs. The part multiplied by b emphasizes quantities, which means that tariffs with higher quantities have a higher score.

We can define $r_{t,i}$ in a similar way:

$$\begin{aligned} r_{t,i} = a \cdot \frac{y_{t,i}}{max_t y_{t,i}} + b \cdot \frac{q_{t,i}}{max_t q_{t,i}}, y_{t,i} = \frac{p_{t,i}}{q_{t,i}}, \\ a + b = 1 \end{aligned} \tag{5.8}$$

The only difference with $c_{t,i}$ is that there is no minus sign in front of a. This is to ensure that higher prices have higher scores, since this results in higher revenues.

We can combine the scores of several days by defining a smoothed score. This smoothed score of tariff t at day i is defined as:

$$TotalScore(t,i)_{i>(N-A)} = \alpha \cdot score_{t,i}(\tau) + (1-\alpha)TotalScore(t,i-1) \tag{5.9}$$

$$TotalScore(t,i)_{i=(N-A)} = score_{t,i}(\tau) \tag{5.10}$$

$$TotalScore(t,i)_{i<(N-A)} = 0 \tag{5.11}$$

With:

$$A = \begin{cases} Y, \text{if } Y \leq N \\ N, \text{if } Y > N \end{cases} \tag{5.12}$$

in which Y is the number of observations, τ is the tariff type, and i is the day at which the score is calculated. Recent values can be more important by reducing Y and increasing α. For all observation made after $(N - A)$ the first definition of $TotalScore(t,i)$ is used and for day $(N - A)$ the second definition is used. Smoothed scores computed before before $(N - A)$ have a value of 0.

5.5 Imbalances

Tariffs cannot be simply adjusted, because many factors are involved in managing the offered tariffs. An important factor is balancing. Creating a balanced portfolio is a key factor in being a successful broker. We only take certain actions depending on the balance in the portfolio. We can define three scenarios: A small imbalance, a big imbalance resulting from a high consumption, and a big imbalance resulting from a high production. We can define the Scenarios as:

- Scenario 1: $\frac{e_{c,i} - e_{p,i}}{e_{c,i} + e_{p,i}} \leq \theta$ and $\frac{e_{p,i} - e_{c,i}}{e_{c,i} + e_{p,i}} \leq \gamma$
- Scenario 2: $\frac{e_{c,i} - e_{p,i}}{e_{c,i} + e_{p,i}} \geq \theta$
- Scenario 3: $\frac{e_{p,i} - e_{c,i}}{e_{c,i} + e_{p,i}} \geq \gamma$

In which $e_{p,i}$ is the smoothed total amount of energy produced at day i and $e_{c,i}$ is the smoothed total amount of energy consumed at day i. Exponential smoothing is used to calculate the values of $e_{p,i}$ and $e_{c,i}$. This method is the same method as the method used in equations 5.9, 5.10, and 5.11 (the same parameters are used). By replacing $TotalScore(t,i)$ with either $e_{c,i}$ or $e_{p,i}$ and by replacing $score_{t,i}(\tau)$ with $energy_{(p \vee c),i}$ (the amount of energy produced or consumer at day i), the equation can be used to calculate $e_{c,i}$ or $e_{p,i}$. θ and γ are threshold values for determining the scenario. Since scenario 2 is probably more common (since there are often more consumers than producers) and thus more difficult to avoid, we make sure that $\theta \geq \gamma$. Each scenario has specific actions and some actions are taken in all scenarios. These actions are described in the following subsections.

5.5.1 Actions taken in every scenario

In all scenarios, we compare the rates of the best performing consumption tariff with the best performing production tariff. Both tariffs have the highest score for their Power type. If a rate of a specific hour of the consumption tariff is lower than the rate of the production tariff of that hour, then we would change both of these rates. At first the difference between the rates is computed. After this, the rate of the consumption tariff is raised by f % of this difference and the rate of the production tariff is decreased by g % of the difference. We use the conditions $f + g > 100$ and $f > g$ to make sure that the rates of consumption tariffs are lower than the rates of production tariffs and we also make sure that the changes in rates are more favorable for consumption tariffs . By raising the consumption tariff with a lower percentage than the percentage by which the production tariff is decreased, we emphasize that it is more important to attract consumers than producers, because more consumers than producers are active on the tariff market. Because of the change in tariff rates for a specific hour, the rate of the consumption tariff will be higher than the rate of the production tariff for that hour. This should avoid unprofitable situations.

5.5.2 Actions taken in scenario 1 (small imbalance)

In this scenario the imbalance is not big. We can thus add new producer and consumption tariffs. Before we add tariffs, we calculate the total scores of the tariffs. If any of these scores is equal or below a certain threshold ψ, we will revoke this tariff and we will alter it. For consumption tariffs we compute the price difference between the rates of the alerted tariff and rate of the best performing production tariff. We would reduce the rates of the adjusted tariff by ϕ multiplied with this difference. This new rate $p_h(t)^{new}$

can be defined as

$$\begin{aligned} p_h(t)^{new} &= p_h(t) - d_{t \in C}(h) \\ d_{t \in C}(h) &= \phi(p_h(t) - p_h(j)) \\ j &\in max_{u \in P} TotalScore(u, i) \end{aligned} \tag{5.13}$$

in which t is the altered tariff, h is the hour of the day, i is the current day, C is the set of consumption tariffs and P is the set of production tariffs. $p_h(t)$ is the rate of tariff t at hour h and $p_h(j)$ is the rate of the production tariff with the highest score (tariff j) at hour h. The rate is computed for each hour, of the day which means that all rates of the tariffs are changed. Similarly we can define the actions taken production tariffs. For production tariffs, we would compute the price difference between the rate of the adjusted tariff and the lowest rate of all consumption tariffs. We would raise the price by ϕ multiplied with this difference. This new rate $p_i(t)^{new}$ can be defined as:

$$\begin{aligned} p_h(t)^{new} &= p_h(t) + d_{t \in P}(h) \\ d_{t \in P}(h) &= \phi(p_h(j) - p_h(t)) \\ j &\in max_{u \in C} TotalScore(u, i) \end{aligned} \tag{5.14}$$

in which t is the altered tariff, h is the hour of the day, i is the current day, C is the set of consumption tariffs and P is the set of production tariffs. $p_h(t)$ is the rate of tariff t at hour h and $p_h(j)$ is the rate of the consumption tariff with the highest score (tariff j) at hour h.

5.5.3 Actions taken in scenario 2 (big imbalance (more energy is consumed than produced))

In this scenario we have a serious imbalance that has to be resolved. We would not offer any new consumption tariffs in this scenario, because this could only make the imbalance worse. Instead we only offer production tariffs. These new production tariffs would be computed in the same way as in scenario 1, which means that all production tariffs with a score of ψ or lower will be improved. We will also compute the production tariff with the highest score by raising its rates by ϕ multiplied with the difference between the rates of this tariff and the rates of the consumption tariff with the highest score. Using the same notations as in the previous section, we can define this new rate as:

$$
\begin{aligned}
p_h(t)^{new} &= p_h(t) + d_{t\in P}(h) \\
d_{t\in P}(h) &= \phi(p_h(j) - p_h(t)) \\
t &\in max_{u\in P} TotalScore(u, i) \\
j &\in max_{u\in C} TotalScore(u, i)
\end{aligned} \tag{5.15}
$$

in which t is the production tariff with the highest score and j is the consumption tariff with the highest score. The other notations are the same as previously described. The rate of each hour of a day in a tariff is altered. If however, after several rate changes, the imbalance does not change in more than one day, we slowly increase the rates of the best performing consumption tariff (the consumption tariff with the highest score), so that our energy demand reduces and this would also allow the production tariffs to rise quicker. In this case the rates of the best performing consumption tariff would be raised by ϕ multiplied with the difference between the rates of this tariff and the rates of the production tariff with the highest score.

5.5.4 Actions taken in scenario 3 (big imbalance (more energy is produced than consumed))

In this scenario we have a serious imbalance that has to be resolved. We would not offer any new production tariffs, because this could only make the imbalance worse. Instead we only offer consumption tariffs. These new consumption tariffs would be computed in the same way as in scenario 1 , which means that all consumption tariffs with a score of ψ or lower will be improved. We will also compute the consumption tariff with the highest score by lowering its rates by ϕ multiplied with the difference between the rates of this tariff and the rates of the production tariff with the highest score. Using the same notations as in the previous section, we can define this new rate as:

$$
\begin{aligned}
p_h(t)^{new} &= p_h(t) - d_{t \in P}(h) \\
d_{t \in P}(h) &= \phi(p_h(t) - p_h(j)) \\
t &\in max_{u \in C} TotalScore(u, i) \\
j &\in max_{u \in P} TotalScore(u, i)
\end{aligned}
\tag{5.16}
$$

in which t is the consumption tariff with the highest score and j is the production tariff with the highest score. The other notations are the same as previously described. The rate of each hour of a day in a tariff is altered.

If however, after several rate changes, the imbalance does not change in more than one day, we would slowly decrease the rates of the best performing production tariff (the production tariff with the highest score), so that our supply of energy will decrease and this would also allow the consumption tariffs to decrease quicker. In this case the rates of the best performing production tariff would be reduced by 2ϕ multiplied with the difference between the rates of this tariff and the rates of the consumption tariff with the highest score. This percentage is higher than in scenario 2, because it is more difficult to make money in this scenario, since we buy more energy than we sell and therefore we can easily lose money if the price differences are small and the imbalance is big.

5.6 Copying tariffs

Before tariffs are copied, we analyze the classes of the consumption tariffs that we have published. When we copy consumption tariffs, we only copy one class and we want to be sure that most classes perform well. Therefore we try to make sure that the differences between the rates of the classes are small. We do this by identifying the tariffs with lowest average rates during the peak-hours of either the household class or the factory/office class. If the difference in average rates is higher than ω, then we publish the tariff with the highest rate with a new rate for the peak-hours of its class. This rate is the average rate of the class peak-hours of the other Tariff. By doing this, we make sure that there is not a big difference between the classes. A big difference in tariff rates is probably not favorable, because this could result in a portfolio that consists of tariffs attracted by customers belonging to a single type, which could result in more balancing issues, because more energy is consumed at a certain part of the day. This portfolio might be able to become more balanced if the rates of the tariffs of the other classes are priced more competitively. This might also attract more customers.

In selecting tariffs we want to copy, we follow several steps. The steps taken depend on the imbalance scenario. In scenario 1, both producers and consumers are copied, in scenario 2 only production tariffs are copied. In scenario 3, only consumption tariffs are published. Besides the specific actions for each scenario, we can also copy a consumption tariff for other reasons. To see if we should do this, we follow a set of steps:

- First we analyze all the consumption tariffs in the ordered list belonging to the worst performing class. The creation of this list is described in the next subsection

- Then we pick a tariff from this list in the same way as is described in the next subsection. When no tariff is chosen, we pick the last tariff in the ordered list

- If the tariff picked from the list has a lower overall average rate than the average rate of the best performing production tariff, then the 3 production tariffs with the highest scores are alerted and the consumption tariff is copied in the same way as is described in the next subsection, unless no tariff is chosen, in which case we simply deduce ϕ multiplied with the difference between the consumption tariff's rates and the new production tariff's rates from the copied tariff's rates. The new production tariffs have a rate that is 99% of the rate of the copied consumption tariff for the hours in which their rate is lower than the rate of the copied consumption tariff.

Doing this allows us to create tariffs with lower consumption rates than our competitors when we copy a tariff. The tariff market is a market that is mainly used to attract consumers, so it is important to be the agent that can attract the most consumers.

A consumption tariff is also copied in scenario 2 if an ordered list of the worst performing class has at least one tariff. The adjusted competing tariff is the consumption tariff with the highest and thus most unattractive average rate of the peak hours of its class. The new rate of this tariff is computed by lowering the tariff's rates by ϕ multiplied with the difference between its rates and the rates of the production tariff with the highest score. By copying this consumption tariff we make sure that the consumption tariffs stay competitive, but since we copy the worst performing consumption tariff, the influence on the adjustment of the production tariffs is not noticeably big, since the most attractive consumption tariff in our own set of tariffs probably won't change and if it does, the change is probably not big. How the scenario-specific consumption and production tariffs are copied is explained in the next couple of subsections.

5.6.1 Copying consumption tariffs

For copying consumption tariff we follow several steps:

- First we classify the competitors tariffs according to the classification method that is described in section 5.2.
- Following this, we determine which class is the worst performing class of our currently published tariffs. To determine this, we accumulate the scores of peak tariffs, household tariffs, and office / factory tariffs in our portfolio. We can define the accumulated score of tariff type τ at the current day i out of the set of tariffs T as:

$$TypeScore_i(\tau) = \sum_{t \in T \wedge Type_t = \tau} TotalScore(t, i) \tag{5.17}$$

  in which i is the current day, t is a tariff, τ a tariff type and $Type_t$ is the type of tariff t. The type of tariff with the lowest accumulated score is our worst performing class. If the worst performing class is a peak tariff, then we use an office / factory tariff as our worst performing class, because the consumption pattern of the customers of this type are closer to the production pattern of the producers and therefore using this class might reduce imbalances.

- After determining the worst class of the tariffs, we create an ordered list of competitor tariffs belonging to this class. Peak and flat tariffs are included in this list too, because they are not aimed at a specific customer and they can thus belong to any class, including the worst performing class. These tariffs are ordered according to their average rate during the peak hours of the class they have been classified to.

- Once we have ordered the list, we are going to iterate through the list, starting at the beginning of the list, which contains the tariff with the lowest average rate. For this tariff, we compute a smoothed difference. This difference is based upon the changes in rates between this tariff and tariffs to which this tariff is related. An explanation about this difference can be found in section 5.6.3.

- This difference is used in defining a new rate for the peak-hours of the class of the tariff that we try to publish. We shall use the average rate during the peak-hours of the class of the tariff we try copy, the average class rate, in our comparisons. In defining the new rate, we first subtract ι multiplied with the difference from the average class rate of the consumption tariff that we try to copy. If this new rate is below the average rate of the production tariff with the highest score, then we attempt to publish the tariff. If not, then we try to subtract κ multiplied with this difference and if this is also below the average rate of the best production tariff, we subtract the computed smoothed difference and if that is also lower than the average rate of the best production tariff, we check if the current average class rate of the copied tariff is below the average rate of the best production tariff and if that is not the case, then we subtract ϕ multiplied with the difference between the average class rate and the average rate of the best performing production tariff from the average class rate and we use this rate to publish the tariff.

- If any rate we have computed before was higher than the best production tariff, then we try to publish the tariff with this rate. If the average class rate continues to be below the production tariff, we move on to the next tariff in the list. If no tariffs are left, then no consumption tariffs are offered. If a tariff is left, then this tariff is published and the rate we have computed in this iteration is used as the rate for class peak-hours in our new tariff. The other rates are decreased by ϕ multiplied with the difference between the found tariff's consumption rates and the best performing production tariff's rates. There is however one exception. If there is a single rate that is lower than the best production tariff's rate, than a rate that is 101% of the production tariff's rate of that hour replaces this single rate. By doing this, the rate is slightly higher than the production tariff, but not much higher, because it should not differ too much from its old rate.

5.6.2 Copying production tariffs

Production tariffs are computed in a similar way as the consumption tariff. First an ordered list of competitor production tariffs is made. Tariffs with higher rates appear first in this list. Once this list has been created, we can start iterating through it. For each tariff in the iteration, we compute a smoothed difference, which is described in section 5.6.3.

We use this difference to try to compute a new rate for the copied tariff. First we increase the average rate of the production tariff in the list by ι multiplied with this difference. If this rate is higher than the average rate of the consumption tariff with the highest score, then we compute a new rate, which is an increase of the average rate by κ multiplied with this difference. When this rate is also higher than the average rate of the best consumption tariff, then we check whether a rate that is just increased by the computed smoothed difference is higher than the average rate of the best consumption tariff. If this is also case, then we perform our final check: we check if the average rate of the production tariff we try to copy is higher than the average rate of the best consumption tariff. If this is not the case, then we increase the production tariff by ϕ multiplied with the difference between the average rate of the production tariff and the average rate of the best consumption tariff and we use this rate to publish the tariff. If any rate we have computed before was higher than the best consumption tariff, then we try to publish the tariff with this rate.

5.6.3 Computing differences

For computing differences between tariffs we compute a smoothed difference. This difference is a prediction of the difference in rates between a new tariff that the competing agent will create and the tariff that we try to copy. The difference is based upon the differences in rates of the tariff that we try to copy and the tariffs that this tariff has superseded. By analyzing these tariffs, we can analyze the development of the rates. We only analyze rates of the class of the tariff that we intend to copy. For example, for an office / factory tariff, we would only take the rates during the hours 9-16 into account. Sometimes tariffs might not have tariffs that it superseded. In that case, we can create links between tariffs, which is explained in section 5.6.4. We can define a smoothed difference as:

$$Difference(p_i) = \alpha \cdot \delta(p_i) + (1 - \alpha) \cdot \delta(p_{i-1}) \tag{5.18}$$

with

$$\delta(p_i) = \overline{p_i} - \overline{p_{i-1}} \tag{5.19}$$

$$\delta(p_o) = \overline{p_0} \tag{5.20}$$

$$\alpha \in [0, .., 1] \tag{5.21}$$

$$i \geq 1 \tag{5.22}$$

where $\delta(p_i)$ is the difference between the average class rate of tariff i and the average class rate of tariff $i - 1$. The lowest possible i is 1 and for computing $\delta(p_1)$, we use $\delta(p_o) = \overline{p_0}$. The tariff we try to copy is tariff n. When the smoothed difference is positive (for producers) or negative (for producers), then we define the smoothed difference as 30% of the difference between the average class rate of tariff i and the best performing production (if tariff i is a consumption tariff) or consumption tariff (if tariff i is a production tariff) .

5.6.4 Creating links

When a tariff has no tariffs that it supersedes, we need to create links between tariffs. We have no information about the links between the tariffs and therefore we are forced to create these links on the basis of several assumption. The most important assumption is that agents attempt to make their tariffs more attractive by lowering (for consumers) or increasing (for producers) the rates of their tariffs. This is a realistic assumption, since lowering or increasing the tariff's rates allows the agent to attract more customers. New tariffs should therefore have more attractive rates than old tariffs. If no old tariff has less attractive rates, then we do not even have to use the algorithm, because it would not lead to a result that could boost the performance of our agent (the copied tariff would be too bad). New tariffs are however continuously created and these tariffs have to be linked to old tariffs. We try to link a new tariff to the old tariff that has the most attractive rates that are less attractive than the rates of the new tariff. For a consumption tariff we would for example link the new tariff with an old tariff that has the lowest possible rate under the condition that this rate is higher than the rate of the new tariff. We assume that we can link these tariff, because the old tariff is the most similar tariff compared to the new tariff and this new tariff has rates that are less attractive than the new tariff. It can thus be said that tariffs are linked on the basis of a conditional similarity of tariffs with the condition being that the new tariffs have to be more attractive than the old tariffs. The rates we use in our linking algorithm are averaged rates based on the class of the tariff. This, for example, means that a tariff that is classified as an office / factory uses the average rate during office hours. Sometimes a tariff is linked to a tariff that is already part of a link. In this case we add the tariff to the last tariff of this link. If there are multiple links, we add the tariff to the end of the link that has a tariff at the end of the link that has rates that are most similar to the rates of the tariff that we try to link it with. Our algorithm is described in Algorithm 1.

We have tried to clarify this algorithm in Figure 5.2. In this Figure we assume that

Algorithm 1 Create links

for every competing broker b **do**
  for every new tariff i of broker b **do**
    compute average rate $\overline{p_{i,\tau}}$ of class τ for each tariff i
    define the most attractive class rate of the old tariffs as m and the tariff belonging to this rate as f
    for every old tariff j of broker b belonging to class τ **do**
      compute average class rate $\overline{p_{j,\tau}}$ of class τ for each tariff j
      if $\overline{p_{j,\tau}} < \overline{p_{i,\tau}}$ and $\overline{p_{j,\tau}}$ is more attractive than m or m has no value **then**
        $m = \overline{p_{j,\tau}}$
        $f = j$
      end if
    end for
    if tariff f is not an end-node of a list of superseding tariffs **then**
      link tariff i to tariff j
    else
      find set L that consists of lists that have tariff f as a tariff it supersedes
      if set L has only one list **then**
        link tariff i to the last tariff in list $l \in L$
      else
        define the rate a as the rate that is the closest to $\overline{p_{i,\tau}}$ and the tariff w as the tariff belonging to this rate
        for every list $l \in L$ **do**
          compute the average class rate $\overline{p_{l,\tau}}$ for the last tariff in list l
          if $\overline{p_{l,\tau}}$ is closer to $\overline{p_{i,\tau}}$ than a or a has no value **then**
            $a = \overline{p_{l,\tau}}$
            w is defined as the last tariff in list l
          end if
        end for
        link tariff i to tariff w
      end if
    end if
  end for
end for

all tariffs belong to the same class and broker and all tariffs are consumption tariffs. All rates that are displayed in the Figure are average rates. At first we have a set of initial tariffs 1,2 and 3. At a certain timeslot, 3 new tariffs are added (4,5 and 6). The lowest rate that is higher than 0.32 is 0.4, which is the rate of tariff 2 and therefore tariff 4 is linked to tariff 2. 0.4 is also the lowest rate that is higher than 0.35 and therefore also tariff 5 is linked to tariff 2. Please note that we only compare new tariffs with old tariffs and new tariffs are not compared with each other. Tariff 6 has a rate of 0.22 which is lower than 0.3 and, since there are no old tariffs with lower rates, tariff 6 is linked to tariff 3. An interesting situation can be seen when the new tariffs 7, 8, and 9 are introduced. The lowest rate higher than 0.33 is 0.35 and therefore tariff 7 is linked to tariff 5. The lowest rate that is higher than 0.38 is 0.4, the rate of tariff 2. However, tariff 2 is linked with two other tariffs. Therefore we link tariff 8 with tariff 5, the tariff with the rate that is closest to Tariff 8. Tariff 9 is linked to Tariff 1, since its rate is between 0.4 and 0.5.

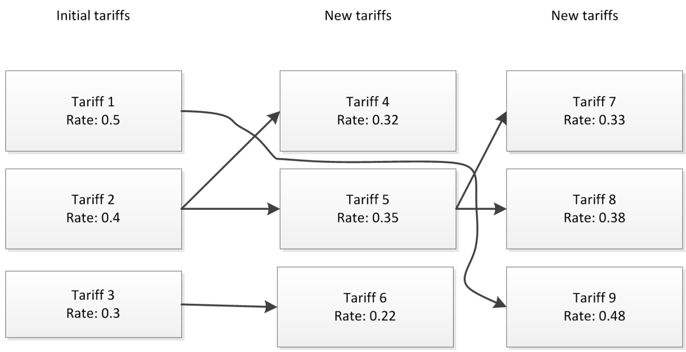

Figure 5.2: Adding links for consumption tariffs

5.6.5 Overview

To summarize the copying of tariffs, we can use Figure 1.3. This Figure contains a global description of our copying mechanism. Some details in this Figure are missing (such as the specific tariff adjustments described in the introduction of this section) and these details can be found earlier in this section, but other than that, the Figure can give us an overview of how our copying mechanism works.

First we have a set of new tariffs of competitors. We classify them according to the method described in section 5.2 and we determine the worst performing class. After this, we check if there are any tariffs that have no tariffs it supersedes. When this is the case, links between tariffs are created using the method described earlier in this section. After this, we create an ordered list of tariffs belonging to the worst performing class, in which the tariffs with the most attractive rates appear earlier in the list. We pick the first tariff in this list and we compute the smoothed difference for it. With this difference, we try to adjust the rates of the tariff. When the adjustment of the tariff's rates fails, we pick the next tariff in the list and we try to adjust this tariff. This continues until the tariff adjustment is successful or until there are no more tariffs left. If the tariff adjustment is successful, we offer the newly adjusted tariff to the market. If there are no more tariffs left, we do not offer any tariffs to the market.

5.7 Summary

The overview of our agent framework is depicted in Figure 5.1 in the beginning of this chapter. At the start of the game, our agent publishes a set of initial tariffs. These tariffs become a part of our portfolio. For each tariff in our portfolio we calculate a score that takes the aspects of variability and profitability into account. Consequently we determine an imbalance scenario, which depends on the amount of energy that we buy and sell. For a specific imbalance scenario, specific actions are executed. The scores that we have computed earlier are used in these actions. Depending on the imbalance scenario, we can also copy and alter some tariffs. When we copy tariffs, we take several aspects, such as the performance of our tariffs in relation to their class or the changes in tariff rates, into account. After the agent has copied and altered competitor's tariffs, it has completed its set of actions for that timeslot.

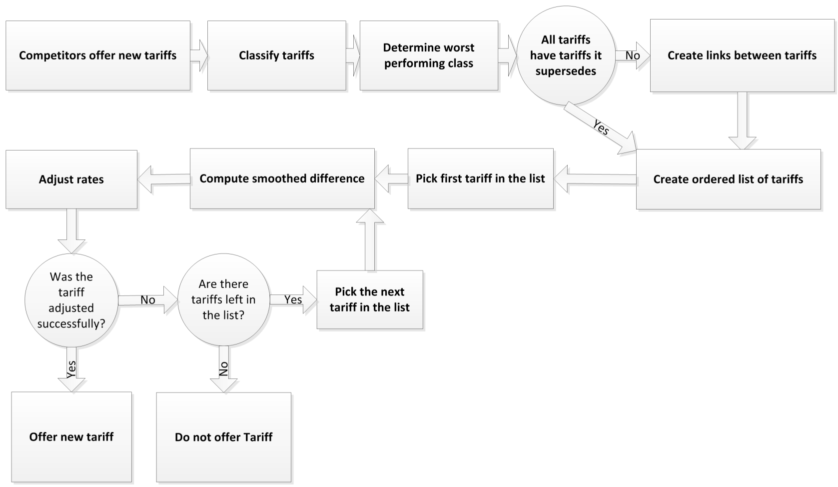

Figure 5.3: The process of copying a tariff

Chapter 6

Experiments

6.1 Introduction

To test the effectiveness of our framework, we need to test it in an experimental setting, which is described in this chapter. In section 2 we describe the general experimental set-up, while section 3 describes the results of the experiments. In section 4, we summarize this shapter and we have a discussion about our results.

6.2 Experimental set-up

6.2.1 Market set-up

The set-up of the market is fixed for all games. The market consists of several customers. The customer models are based on the customer models that were created by Kevin Meijer and these models are described in our Simulation Framework. We assume that when all customers are subscribed to one agent and there is no variance, then the agent sells 26% more energy than it buys, which means that the total base value of the consumers is 26% higher than the base value of the producers. We choose to have more consumers than producers, because in most energy markets, more consumers are active on the tariff market than producers. This undoubtly causes some imbalances, but normally these imbalances can be solved on the wholesale market, since energy is mainly bought on the wholesale market.

All customers are summarized in Table 6.1.

Table 6.1: Customers in the Simulation

Customer	Type	Power Type	Base value	Deviation (%)	Amount of customers
Basic Household	Household	Consumption	2000	8	6
Basic Office	Office	Consumption	2200	15	4
Basic Factory	Factory	Consumption	4400	38	1
Producing Office	Office	Production	2000	20	5
Producing Factory	Factory	Production	5000	45	2

The total consumed energy is thus 25200 kW, which is 5200 kW more than what is produced. The energy produced by producers is generally more variable than the energy that is consumed by consumers, which reflects external factors (such as the Weather) that can have an influence on producers (Windmills produce less when there is less wind for example). In the market we have simulated, the customers pick a tariff each hour on the first day. This gives the market some time to stabilize itself. After 24 timeslots, the customers pick a tariff every day.

6.2.2 Agent types

For our experiments we use three type of agents: the Standard Agent, the Score Agent and the Copy Agent. Each agent has to follow a fixed set of rules, which are:

- The rate of the best performing consumption tariff has to be higher than the rate of the best performing production tariff, because otherwise energy is bought at a higher price than at which it is sold

- The average rate over the entire day (24 hours) has to be the same for the first tariffs that are published by the agents. By doing this, the performance of the agent is mainly determined by the way they adjust their tariffs, which is what we want to investigate.

- All tariffs that are published in the first timeslot, need to have lower rates during off-peak hours (hours: 23-6), because tariffs often have lower rates during these hours in real-life energy markets, since this could spread the energy consumption on a day more evenly.

The Standard Agent is the most basic agent. This agent offers 2 tariffs: One consumption tariff and one production tariff. The consumption tariff has a rate of 0.99 during peak hours and 0.59 during off-peak hours. The production tariff is a flat tariff with a rate of 0.20. The size of the difference between the consumption and production tariff gives the agent possibilities to change its tariffs. The Standard agent only adjusts its tariffs if one of its tariffs does not have any transactions in the previous timeslot. The tariff is adjusted by increasing (for production tariffs) or decreasing (for consumption tariffs) its tariff rate by 30% of the difference between the rate of the consumption tariff and the production tariff. This adjustment is only performed when the consumption tariff has a rate that is higher than the production tariff, which is needed to obey the first rule that is described in the beginning of this subsection.

The Score Agent utilizes all sections of our Agent Framework, except for the part that involves copying and adjusting tariffs of other brokers. Initially this agent offers 4 tariffs: One production tariff and three consumption tariffs. The production tariff is a flat tariff with a rate of 0.20 and the three consumption tariffs can be divided into different classes and they are priced according to these classes. These classes are: "Household", "Office", and "Peak". The average daily rates during peak hours (07:00-22:59) of these tariffs are the same as the average daily rates of the tariffs of the Standard Agent, but the rates are not flat (except the tariff with the class "Peak", which is flat during peak-hours), so at some hours the rates might be higher or lower than the Standard Agent's tariffs. This depends on the class of the tariff. A Household has lower rates during household peak hours (07:00-08:59 and 17:00-22:59), but higher rates on office peak hours (9:00-16:59), for example. The rate during the peak-hours of one class is 0.95 and the rate during the peak-hours of the other class is 1.03. The tariffs also have lower rates during off-peak hours, since tariffs often have lower rates during these hours in real-life energy markets. The rate during off-peak hours is 0.59, which is also the non-peak hour rate of the Standard Agent.

The Copy Agent has all the properties that are described in the Agent Framework, including the part that involves copying and adjusting tariffs of other agents. The first tariffs posted by this Agent are the same tariffs that the Score Agent publishes.

The functions of each agent are summarized in Table 6.2 and the rates are summarized in Table 6.3, in which the Peak tariff is the Peak tariff published by the Copy and Score Agent and it is also the Standard Agent's consumption tariff. The Household tariff and the office / factory tariff are the class specific tariffs published by the Copy and Score Agent.

Table 6.2: Functions of the Agent

Function	Standard Agent	Score Agent	Copy Agent
Adjust tariffs with no transactions	yes	yes	yes
Use scores to rank tariffs	no	yes	yes
Imbalances are used in decisions	no	yes	yes
Price tariffs according to their class	no	yes	yes
Copy and adjust other Agent's tariffs	no	no	yes

Table 6.3: Rates of tariffs per hour

hours	Peak Tariff	Household tariff	Office/Factory tariff
00:00-06:59	0.59	0.59	0.59
07:00-08:59	0.99	0.95	1.03
09:00-16:59	0.99	1.03	0.95
17:00-22:59	0.99	0.95	1.03
23:00-23:59	0.59	0.59	0.59
24-hour average	0.857	0.857	0.857

In our experiments we compare each agent with each other. agents with more advanced techniques should perform better. To test this, we use several scenarios. In these scenarios the Copy Agent competes with either the Score Agent or the Standard Agent.

The Score Agent also competes with the Standard Agent. In most scenarios, all three the agents compete with each other. In some scenarios we also test a market in which agents do not indicate what their previous tariff was (non-superseding tariffs). Normally they do indicate this (these tariffs are called superseding tariffs). By testing this, we can see whether the linking mechanism of the Copy Agent works correctly.

6.2.3 Parameters

Fixed parameters in the Agent Framework

All parameters of the agents are fixed. We start by setting the parameters of the score mechanism described in section 3 of our Agent Framework. For a score $score_{t,i}(Co)$, described in equation 5.2, or a score $score_{t,i}(Pr)$, described in equation 5.3, we set α to 0.15 and β to 0.85, to emphasize the emphasis we give to revenues. In the cost element c_t and the revenue element r_t, we give a value of 0.2 to a and a value of 0.8 to b, which emphasizes the role of the quantities. For the smoothed total score $TotalScore(t,i)$, described in equations 5.9 and 5.10, we select an A of 3 and an α of 0.92 to emphasize more recent values. These values are also used for computing the smoothed total amount of energy consumer or produced. For the imbalance scenarios described in section 5.5, we set threshold θ to 0.3 and threshold γ to 0.05, which means that an imbalance scenario with more consumers than producers is preferred. The parameter f, used to lower the rate of a consumption tariff if this rate is lower than the rate of a production tariff, is set at 21% and the parameter used to increase the rate of the production tariff, g, is set at 81%. By doing this, we emphasize the role of attracting consumers, since f is remarkably lower than g. The parameter ϕ, which is used for computing differences in section 5.5 of this thesis, is set at 0.3, which makes sure that the change in tariff rates is not big, but also not small. The parameter ψ that is mentioned in section 5.5 is set at 0, which means that only tariffs with a score of zero or lower are going to be improved. We have set the parameter ω, which was discussed in section 5.6, at 0.02, which means that differences between the rates of tariffs of different classes need to be quite small. The parameters ι and κ are used to change the rates of copied tariffs. This is described in section 5.6. We set ι to 2.01 and κ to 1.05, which means that we initially try to compute a difference that is bigger than the difference that we predict, which should ensure that our tariffs stay as competitive as possible. The smoothed difference $Difference(p_i)$, described in equation 5.18, has an α of 0.4.

Fixed parameters in the simulation environment

The variable balancing costs c_0, mentioned in section 4.6, are fixed at 0.4 These costs are fixed because balancing is not the most important part of these Thesis. The amount of timeslots is also fixed at 647.

6.2.4 Scenarios

We have used several scenarios to test our Agent. We started by analyzing the influence of rationality on the results and after that we have investigated scenarios with only two agents. Our last scenarios dealt with the effect of inertia on the results.

To investigate the influence of rationality, we have varied the parameter λ, because this variable is used to measure the rationality of a customer in the logit choice model for picking a tariff. We use the following λ values: 0, 1, 5, 10, 25, 50, 100, 300, 500, and 600. 600 is the highest value we've used, because Java does not allow us to compete higher λ values, since this might result in the value 'infinity', which is something that we cannot use in our model. In some scenarios, the λ is chosen randomly. This is described in section 6.3.2. A description of the logit choice model we used can be found in the chapter about our Simulation Framework.

The customers described in the second section of this chapter are fixed in terms of their base value and deviation, but not in terms of their alphas. In the last scenarios the alphas are changed to investigate the effect of inertia on the customers. Initially, a_{costs} is set at 0.85 and $a_{inertia}$ is set at 0.15, but for some simulations $a_{inertia}$ can have the following values: 0, 0.15, 0.3, and 0.5. For these simulations, we set α_{costs} to: $\alpha_{costs} = 1 - \alpha_{intertia}$. In our last scenario, $a_{inertia}$ is chosen randomly. The equation used to calculate the utility is described in the chapter about our Simulation Framework.

6.2.5 Measurements of performance

We have used the amount of cash earned and the pick rates to determine the success of the agents and they are thus the measurements of performance that we have used.

The amount of cash is the amount of cash on the bank account of each Agent at the end of the game. Cash is added to this account when customers, that are subscribed to the Agent's consumption tariffs, consume energy. Cash is subtracted from this account when producers, subscribed to the Agent's production tariffs, produce energy and the Distribution Utility also charges the agents a fee for the imbalance they have at every timeslot, which is also subtracted from the Agent's bank account. Information about the customers and the distribution utility can be found in our chapter about the Simulation Environment.

A pick rate is a percentage that expresses how many times a certain customer type has selected a certain agent. For the pick rates of consumers we have used multiple types, which are Households, Offices and Factories. For the pick rates of Producers, only one type was used (the Producer), because no Agent had specific strategies for attracting specific producer types and since all producers have approximately the same peak hours, making these specific strategies is something that is difficult to do.

For both the pick rates and the amount of cash earned, we have computed the average and the standard deviation. We have also used a one-tailed paired T-Test with a significance level of 5% to test for significance. In this T-Test we have computed the difference between the measurement values of the Copy Agent with either the Score Agent or the Standard Agent for every run. The T-test thus consisted of two samples and we assume that they have a heteroscedastic variance. All scenarios were performed 20 times.

6.3 Results

We have computed the results for the scenarios described in section 6.2.4. We have used Java to program our agents and our Simulation Environment. Our results were computed on an ASUS laptop with an Intel Core i7-2630QM CPU with a clock speed of 2.00GHz. The laptop ran on a 64-bits version of Windows 7 Home Premium, server pack 1 and it had 6 GB of RAM.

6.3.1 Rationality

One of the first aspects that we wanted to research is the influence of the rationality on the performance. To do this, we have simulated a market that consists of one Copy Agent, one Score Agent and one Standard Agent. We have used the following values of λ (a higher λ represents more rational customers): 1, 5, 25, 50, 100, 300, 500, and 600. In the simulation, all customers had the same λ.

A graph depicting the cash values of the agents can be seen in Figure 6.1. A Table with these values can be found as Table A.1 in the Appendix. In the Table the average cash values of the agents per λ can be seen, as well as the standard deviation of these agents. The column T-Test shows whether the average cash values of the Copy Broker were significantly higher than the average cash values of other brokers with a significance level of 5%. Similar Tables are used in the remaining parts of this section.

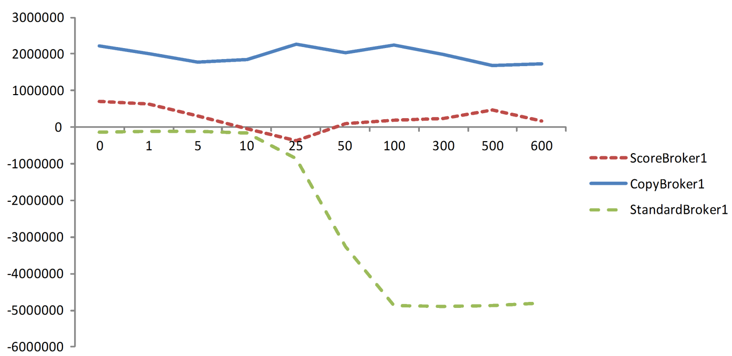

Figure 6.1: Cash values of broker per λ

For all values of λ, CopyBroker1, the Copy Agent, is the best performing broker and the differences are significant. It is notable that after $\lambda = 25$, the Standard Agent starts to lose a lot of money. This can be explained by the pick rates of Producers. A graph depicting these rates is displayed in Figure 6.2.

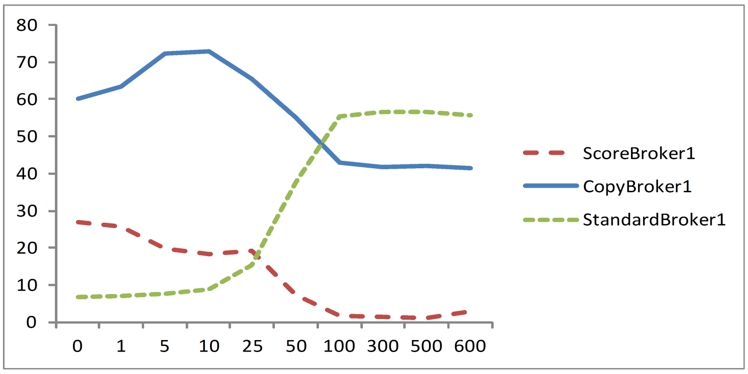

Figure 6.2: Pick Rates of Producers per λ

It is clearly noticeable that the Copy Agent attracts most producers when the λ is low, while the Standard Agent seems to manage to attract most producers for high λ values. This is logical, since the Copy Agent has a strategy that prefers a situation in which there is more consumed than produced compared to a situation in which there is more produced than consumed. There are several reasons for this. One reason is that the Copy Agent alters its 3 best performing production tariffs when a selected consumption tariff has lower rates than the best performing production tariff (the mechanism is explained in more details in our chapter about the Agent Framework). Another reason is that the threshold θ is higher than the threshold γ, which means that a higher imbalance is needed to reach scenario 2, which has specific actions to re-balance a situation in which more energy is bought than sold. These scenarios are discussed in the imbalances section of our Agent Framework. The Standard Agent is indifferent towards these imbalances and therefore it was able to attract most of the producers. It has however failed to do this in situations with a low λ. This can easily be explained by the fact that the Standard Agent only had 1 production tariff, while the other brokers could have had up to 12 production tariffs. Consumers that were less rational made decisions that were more random. In random decisions, the probability of picking a tariff that belongs to a broker with many tariffs is higher than the probability of picking a tariff from a broker with just one tariff. Apparently $\lambda = 25$ is a point at which the utility of tariffs starts to become more important than the quantity of tariffs.

The Copy Agent clearly benefits from the important of the quantity of tariff for less rational customers, because the Copy Agent adds more tariffs per timeslot than other agents and therefore the Copy Agent has most tariffs in the beginning of the game. This stops when this Agent reaches its limit (20 consumption tariffs and 12 production tariffs). In an extreme situation ($\lambda = 0$), the customers eventually randomly pick a tariff between the Score Agent and the Copy Agent, since both agents have approximately the same amount of tariffs near the end of the game. Due to the strong beginning of the Copy Agent, its performance is better than that of the other agents for low λ values.

The Copy Agent is clearly much better in attracting consumers. Most Offices, Factories and Households are attracted to the Copy Agent and the differences are significant. Figure 6.3 depicts the pick rates of Household per λ. The pick rates of Offices and Factories can be found in the Tables A.4 and A.5 in the Appendix. Table A.3 in the Appendix contains the results for the Households.

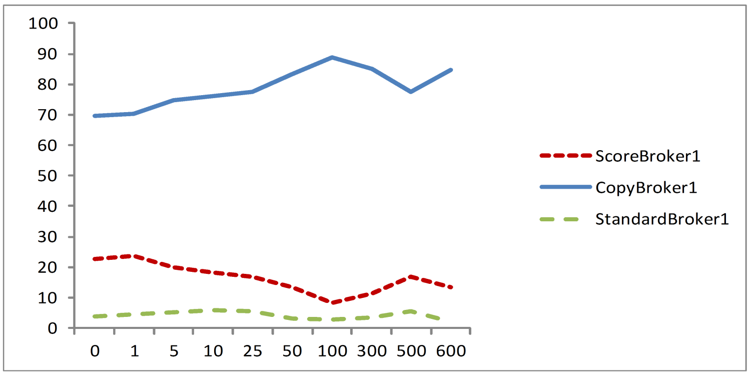

Figure 6.3: Household pick rates per λ

The Copy Agent is thus the best performing Agent in terms of the earned amount of cash and the pick rates of consumers. It is also the best performing Agent in terms of pick rates of producers for low λ values, but not for high λ values.

6.3.2 Heterogeneous Market in terms of Rationality

After testing the different λ values, we have set-up a heterogeneous market. In this market each customer has a λ that is randomly chosen within a specific range. This range depends on the type of customer. Households have a λ that ranges from 1 to 150, while offices and factories have a λ that ranges from 150 to 600. We assume that factories and offices are profit-maximizing companies and they should therefore be more rational than households. The value of 150 was chosen as an upper bound for households. This decision was partially based on an analysis of the probabilities of picking the best tariffs. Suppose that there are 20 tariffs and all tariffs have the same utility, except one tariff that has a slightly higher utility. If the highest utility is 0.4 and the lowest utility is 0.39, then the probability of picking the best tariff, with $\lambda = 150$, is: $\frac{e^{150 \cdot 0.4}}{19 \cdot e^{150 \cdot 0.39} + e^{150 \cdot 0.4}} \approx 0.191$, which is a small probability, but since the differences between the tariffs are small, the decision to pick another tariff is not a bad decision. Now suppose that we have the same situation, except that the most expensive tariff has utility of 0.4 and the other tariffs have a utility of 0.36. In this situation, the probability of picking the most attractive tariff is: $\frac{e^{150 \cdot 0.4}}{19 \cdot e^{150 \cdot 0.36} + e^{150 \cdot 0.4}} \approx 0.955$, which is a high probability. The difference in utility in this situation is also bigger than this difference in the previous situation, which means that customers can benefit more from picking the best tariff and therefore this choice is more important. Customers seem to pick the best tariff more often when the differences between tariffs are bigger. Based on this analysis, we think that $\lambda = 150$ is a good upper boundary for the Households. Analyzing the results from the previous section also gives us a good indication about the effect of λ on the decisions made by the customers. These results clearly indicate that changing λ does not have a big influence on the results after $\lambda = 100$.

The results were tested for a situation in which the agents indicated what their previous tariff was (superseding tariffs) and for situations in which they did not indicate this (non-superseding tariffs). The average cash values can be seen in Tables 6.4 and 6.5. In the Tables, we talk about heterogeneous customers, because they have different λ values. The distribution of of λ among these customers is also used in the upcoming sections.

Table 6.4: Cash values for heterogeneous customers with superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	-396964	1030398	Significant
CopyBroker1	2523757	1147734	
StandardBroker1	-4111641	2335012	Significant

Table 6.5: Cash values for heterogeneous customers with non-superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	-95155,6	645465,5	Significant
CopyBroker1	2988067	746608,7	
StandardBroker1	-4709978	1297010	Significant

For heterogeneous customers, the Copy Agent is also the best performing agent, which is not surprising, since this agent was also the best performing agent in the previous section. An interesting observation is that this is also the case for non-superseding tariffs, which indicates that the Copy Agent is capable of computing differences between tariffs that are linked to each other by the Agent's algorithm. This means that the Copy Agent should be able to perform well in situations where the relationships between tariffs are unknown. In terms of pick rates of consumers, the Copy Agent is clearly the best agent. Table 6.6 and Table 6.7 contain the pick rates of households for a situation with superseding and without superseding tariffs. The pick rates for Offices and Factories can be found in Tables A.6, A.7, A.8, and A.9 in the Appendix.

Table 6.6: Household pick rates for heterogeneous customers with superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	11,98333333%	6,805979%	Significant
CopyBroker1	83,31666667%	8,930842%	
StandardBroker1	4,65%	6,285112%	Significant

In terms of attracting producers, the Copy Agent is not doing better than the Standard Agent. In the beginning of the game, the Copy Agent was the best Agent in terms

Table 6.7: Household pick rates for heterogeneous customers with non-superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	10,53333333%	5,280882%	Significant
CopyBroker1	85,26666667%	5,88148%	
StandardBroker1	4,183333333%	3,313052%	Significant

of attracting producers, but at the end of the game, the Standard Agent is better. More information about the progress of the game per timeslot can be found in the next section. This section also explains the success of the Standard Agent in attracting producers. The overall pick rates of the producers can be seen in Tables 6.8 and 6.9.

Table 6.8: Production pick rates for heterogeneous customers with superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	8%	12,165%	Significant
CopyBroker1	44,05714286%	9,51119%	
StandardBroker1	47,94285714%	18,9944%	Not significant

Table 6.9: Production pick rates for heterogeneous customers with no superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	4,3%	7,323417%	Significant
CopyBroker1	45,95714286%	8,254947%	
StandardBroker1	49,74285714%	11,56159%	Not significant

6.3.3 Single run

To better understand the results we have seen earlier, we have computed the results per timeslot. We did this for a scenario with all 3 agents and we have used averages of 20 simulations. The λ values were distributed among the customers in the way that is described in the previous section. A graph depicting the cash values per timeslot can be seen in Figure 6.4.

The Copy Agent is clearly the best performing Agent in terms of cash. At the start it already managed to make more profit than the other agents and this continues until

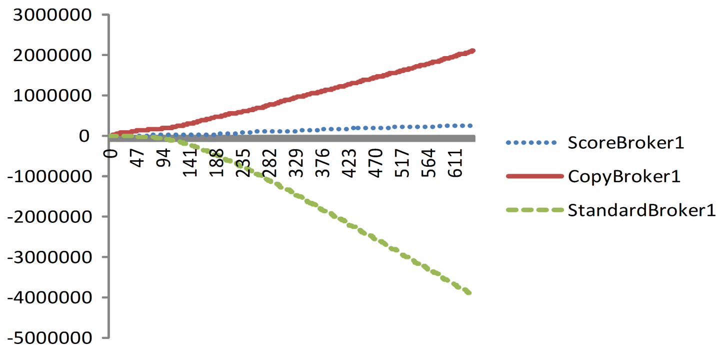

Figure 6.4: Cash per timeslot

the simulation stops. A key part in this success is the Copy Agent's ability to attract consumers. It manages to attract most Households, Offices and Factories. This can be seen in graphs depicting the pick rates of the consumers. The pick rates of the offices are displayed in Figure 6.5. The pick rates of Households and Factories can be found as Figures A.1 and A.2 in the Appendix. Note that these pick rates are not percentages. They are absolute numbers that indicate how many customers are attracted to a certain agent. For example, a pick rate of 3 at timeslot 210 for broker X means that an average of 3 customers of that type are attracted to broker X at timeslot 210.

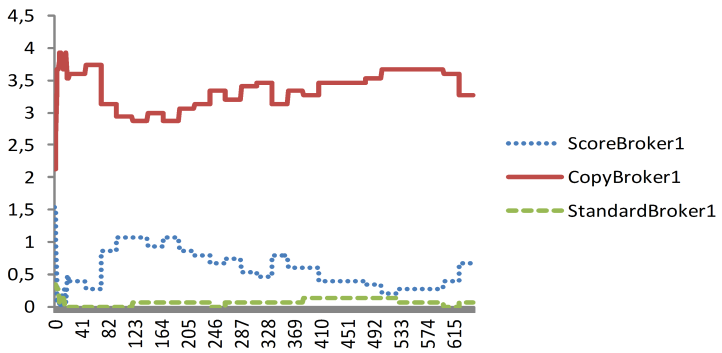

Figure 6.5: Pick rates of offices per timeslot

It is clearly notably that after approximately 100 timeslots, the Standard Agent starts to perform really bad in terms of cash. This is because it manages to attract more producers. To explain this, we use the pick rates of producers per timeslots, which are depicted in Figure 6.6. In the first timeslots, the Copy Agent manages to attract most of the producers. This is easy to explain. In the first phases of the game, the rate differences between tariffs are big and the Copy Agent has more possibilities to change the rates of its tariffs. After a certain amount of timeslots, the rate differences between tariffs decline, which also reduces the Copy Agents ability to change its production rates. Since the Copy Agent has a preference for imbalances with a higher consumption than production, the Copy Agent has a tendency to adjusts its tariffs in a matter that makes them more attractive to consumers instead of producers. For example, the Copy Agent regulatory checks whether there is a competing consumption tariff that has rates that are lower than its best consumption and production tariff. If production tariffs have lower rates than the found consumption tariff, then the rates of the 3 best production tariffs are lowered. The Copy Agent's imbalance strategy is thus a strategy in which the consumption tariffs are priced more competitively than the production tariffs. This causes the Copy Agent to lose most of its production tariffs near the end of the game. It however manages to keep most of its consumption tariffs, which is important, because the tariff market is mainly used to attract consumers. More details about the copying mechanism can be found in the section about copying tariffs in our chapter about our Agent Framework. In some situations the Copy Agent does manage to attract most producers. In these situations the influence of the inertia is different and therefore more information about these situations can be found in the subsection about the influence of the inertia.

6.3.4 Copy Agent vs Standard Agent

After simulating situations with three agents, we have started simulating situations with two agents. We start with a scenario in which the Copy Agent competes with the Standard Agent. The amount of cash earned in this scenario can be seen in Table 6.10 and in Table A.10 of the Appendix.

It seems to be clear that the Copy Agent is the better Agent. This is mainly caused

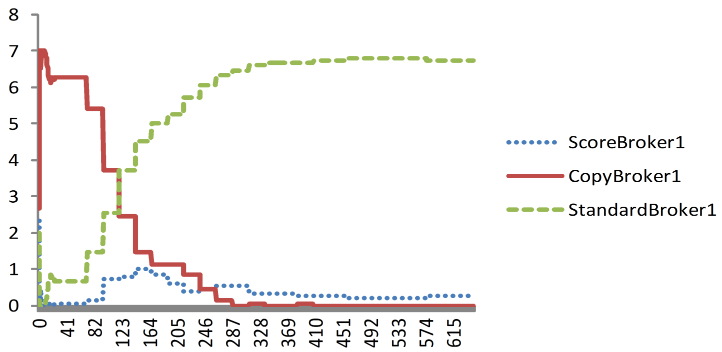

Figure 6.6: Pick rates of producers per timeslot

Table 6.10: Cash Copy vs Standard (superseding)

Broker	Average	Standard Deviation	T-test
CopyBroker1	2753107	569143,6	
StandardBroker1	-3783663	1607818	Significant

by its ability to attract consumers. The pick rates of households can be seen in Table 6.11 and in Table A.11 of the Appendix. The pick rates of Offices and Factories can be found in Tables A.14, A.15, A.12, and A.13 in the Appendix.

Table 6.11: Pick rates of households (superseding tariffs)

Broker	Average	Standard Deviation	T-test
CopyBroker1	92,35%	4,057302%	
StandardBroker1	7,65%	4,057302%	Significant

The mentioned Tables clearly show that the Copy Agent is superior in attracting consumers. It is also better in attracting producers, although it should be noted that most producers were attracted in the beginning of the game, while the Standard Agent managed to attract most of the Producers in the end of the game. If the duration of this game was a bit longer, the results would have probably be different. The pick rates of the producers can be seen in Table 6.12 and in Table A.16 in the Appendix.

Table 6.12: Pick rates of producers (superseding tariffs)

Broker	Average	Standard Deviation	T-test
CopyBroker1	55,62857%	10,36357%	
StandardBroker1	44,37143%	10,36357%	Significant

6.3.5 Score Agent vs Standard Agent

After letting the Copy Agent compete with the Standard Agent, we let the Score Agent compete with it. We only tested a scenario with superseding tariffs, because there is no agent that needs information about links between tariffs. The Score Agent is also able to beat the Standard Agent. The results in terms of cash can be seen in Table 6.13.

Table 6.13: Cash values of the Scenario Score Agent vs Standard Agent

Broker	Average	Standard Deviation	T-test
ScoreBroker1	2163557	2269276	
StandardBroker1	930867	1698231	Significant

The Score Agent was also better in terms of pick pates. For all customers, the Score Agent had a better performance than the Standard Agent. The pick rates of Households can be seen in Table 6.14. The other pick rates can be found in Tables A.17, A.18, and A.19 in the Appendix.

Table 6.14: Pick rates of households for the Scenario Score Agent vs Standard Agent

Broker	Average	Standard Deviation	T-Test
ScoreBroker1	69,11667%	13,19502%	
StandardBroker1	30,88333%	13,19502%	Significant

It is interesting to observe that the percentage of producers that is attracted by the Score Agent is higher than the percentage that the Copy Agent managed to attract in the previous subsection. Apparently the Copy Agent has a stronger preference for consumers in their balancing strategy, which can be explained by the fact that the Copy Agent lowers its production rates if it copies a consumption tariff that has rates that are lower than its own production rates, which strengthens its ability to keep consumers attached to them, but it lowers its ability to keep the producers attached to them.

6.3.6 Copy Agent vs Score Agent

The final Scenario with two agents that we have tested was a Scenario in which the Copy Agent competes with the Score Agent. The results for the cash values of this Scenario can be seen in Table 6.15 and in Table A.20 in the Appendix.

Table 6.15: Cash values for the Scenario Copy Agent vs Score Agent (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	-2490231	1553866,97	Significant
CopyBroker1	3216031	1155666,027	

The Copy Agent is clearly superior in terms of Cash. In terms of pick rates of consumers it is also performing better, as well as in terms of pick rates of producers, although it loses some of its producers near the end of the game, which is caused by the Copy Agent's imbalance preferences. Overall the Copy Agent is still the best performing Agent. The results for the Offices can be seen in Table 6.16 and in Table A.21 in the Appendix. The results for Producers, Households and Factories can be found in Tables A.22, A.23, A.24, A.25, A.26 and A.27 in the Appendix.

Table 6.16: Office pick rates for the Scenario Copy Agent vs Score Agent (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	11,925%	11,81465972%	Significant
CopyBroker1	88,075%	11,81465972%	

6.3.7 The influence of Inertia

After simulating several Scenarios with different agents and different λ values, we think it is time to test another variable. This variable is $\alpha_{intertia}$. By changing this variable, we can make the Inertia component more or less important. This allows is to investigate the effect that changing the Inertia of customers has on the performance of the different

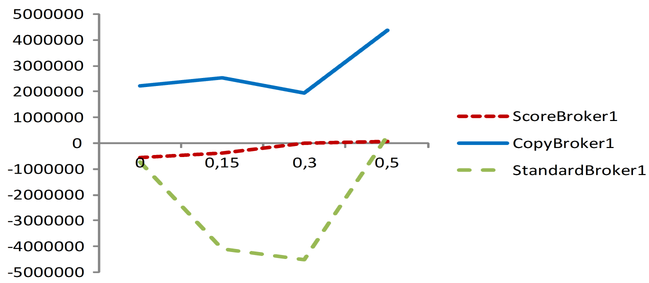

Figure 6.7: Cash values per $\alpha_{inertia}$

agents. To test this, we have used the following values for $\alpha_{intertia}$: 0, 0.15, 0.3, and 0.5. For each value of $\alpha_{intertia}$, we define α_{costs} as: $\alpha_{costs} = 1 - \alpha_{intertia}$. 0 is an absolute extreme in this situation, because with $\alpha_{intertia} = 0$, the customers always pick the tariff with lowest costs .0.5 is the other extreme, because in this situation the customers are very inert and changes in tariff rates have a limited effect on the customer's decision. If for example all consumption tariffs are subscribed to the most expensive consumption tariff and all customers are completely rational, then the other agents would need tariffs with rates that are more than 100% lower than the rates of the second most expensive consumption tariff if they want to attract consumers. We choose not to test a value of $\alpha_{intertia} = 1$, because this would mean that all tariffs stay attached to the Default Broker and therefore any meaningful analysis is not possible. All simulations in this section used superseding tariffs.

A Graph depicting the average cash values per $\alpha_{inertia}$ can be seen in Figure 6.7. A Table with these results can be seen in Table A.28 in the Appendix.

The pattern displayed in the mentioned Figure is quite interesting. For all $\alpha_{intertia}$, the Copy Agent is the best performing agent, but its performance is clearly much better for $\alpha_{intertia} = 0.5$. The performance of the Standard Agent is quite variable. For $\alpha_{intertia} = 0$, the Standard Agent loses a bit of money, but this loss of money quickly increases for $\alpha_{intertia} = 0.15$ and $\alpha_{intertia} = 0.3$. This loss of money is quickly transformed into a profit at $\alpha_{intertia} = 0.5$. To understand these variations, we need to analyze the pick rates. We start by looking at the pick rates of Households. A graph depicting the

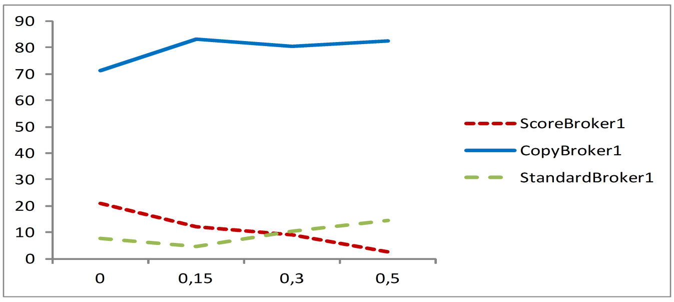

Figure 6.8: Pick rates of Households per $\alpha_{inertia}$

pick rates of Household can be found in Figure 6.8. The pick rates of Households can also be found in Table A.29 in the Appendix. The pick rates of Offices and Factories can also be found in the Appendix as Tables A.30 and A.31.

The Copy Agent managed to attract most of the consumers for all $\alpha_{inertia}$. Its performance is therefore superior in this aspect. The Standard Agent performs better than the Score Agent at $\alpha_{intertia} = 0.5$. The Standard Agent is thus able to get more consumers in the beginning of that game and the Score Agent is not able to get these consumers back due to the high Inertia of the customers. Normally the Score Agent should be able to do this. This is illustrated by the performance of the Score Agent for low $\alpha_{intertia}$ values, which is better than the performance of the Standard Agent for those values. To get a better understanding of the overall market, we need to analyze the producers too, so that is what we did. In Figure 6.9 the pick rates of the producers per $\alpha_{inertia}$ can be seen. More details about this pick rates can be found in Table A.32 in the Appendix.

The pick rates of the producers can clearly tell us something about what is happening. For $\alpha_{inertia} = 0$, the Copy Agent is quite successful in attracting producers, which is something that can be explained. In the beginning, the Copy Agent has most of the producers, but after a while it loses a part of its production tariffs to other agents. This happens sooner in a situation with a low $\alpha_{inertia}$ (such as 0) and therefore this also happens when the differences are smaller. For $\alpha_{inertia} = 0$ the differences can be very small and the differences between the rates of the Copy Agent and the other agents is

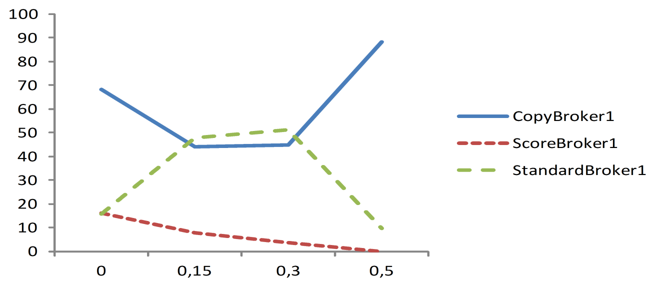

Figure 6.9: Pick rates of Producers per $\alpha_{inertia}$

not as big as in a situation with $\alpha_{inertia} = 0.15$ for example (since bigger rate differences are needed to incentive customers to change their rates when they are more inert). In this situation, it is easier for the Copy Agent to attract producers by changing the rate of its tariffs, so that it can get its producers back and by doing this it manages to keep more producers in its portfolio than in games with a higher $\alpha_{inertia}$ (except very high values (such as 0.5)). In these games the differences in tariff rates might already be too big to overcome, since the rate differences are already bigger when the customer is attracted to another agent and, since these customers are more inert, even bigger rate changes are needed to get these customers back. This can explain the success of the Copy Agent for $\alpha_{inertia} = 0.0$. The Standard Agent manages to profit from the poor performance of the Copy Agent in terms of producer pick rates at $\alpha_{inertia} = 0.15$ and $\alpha_{inertia} = 0.3$. This is however not a good development for the Standard Agent, because it managed to attract many producers, but it did not manage to attract many consumers and therefore the Standard Agent bought energy without being able to sell it. This caused the Agent to perform poorly at $\alpha_{inertia} = 0.15$ and $\alpha_{inertia} = 0.3$ in terms of cash. The high profit of the Copy Agent for $\alpha_{inertia} = 0.5$ can be explained by the fact that it managed to attract most consumers and producers in the beginning of the game. These consumers and producers were probably attracted to tariffs with rates that were higher (for consumptions tariffs) and lower (for production tariffs) than tariffs that appeared later in the game. Due to the high Inertia of these customers, the customers did not switch tariffs and the Copy Agent continued to sell energy at a high price, while buying energy at a low price. Because of this, the Copy Agent made a huge profit.

6.3.8 Customers with different Inertia preferences

In this section we investigate a Scenario with customers that have different preferences for Inertia. We have used an $\alpha_{inertia}$ that ranged from 0 to 0.15 for Offices and Factories, assuming that they are not very inert, because we assume that they are profit-maximizing companies and they are thus more motivated to have lower costs, while Households used an Inertia value that ranged from 0.15 to 0.30, because they are probably less incentivized to switch to another tariff. 0.30 was chosen as the maximal value of $\alpha_{inertia}$, because otherwise the Inertia might have had an impact that was too big. This can be illustrated with an example. Suppose that there are two tariffs with flat rates 0.31 (normalized:$\frac{0.31}{0.55} \approx 0.56$) and 0.55 (normalized: $\frac{0.55}{0.55} = 1$). If an customer consumes 1 kWh each day and the customer has the most expensive tariff as its current tariff, then it would pick the cheapest tariff instead of the most expensive tariff $(-0.7 \cdot 0.56 + 0.3 \cdot 0(\approx -0.392) > -0.7 \cdot 1.0 + 0.3 \cdot 1(= -0.4))$, but this would not be the case if the cheapest tariff had a flat rate of 0.32 $(-0.7 \cdot (\frac{0.32}{0.55}) + 0.3 \cdot 0(\approx -0.407) < -0.7 \cdot 1.0 + 0.3 \cdot 1(= -0.4))$. 0.32 is already noticeably lower than 0.55 and the customer is thus quite inert. We do not want to have situations that are more extreme than this, so therefore we choose 0.3 as our maximum $\alpha_{inertia}$. We have tested this scenario for a situation with superseding and without superseding tariffs.

The results of this Scenario were quite similar to the results we have seen before. The Copy Agent is the best performing Agent in terms of cash, which can seen in Table 6.17 and in Table A.33 in the Appendix.

Table 6.17: Cash values for a Scenario with mixed $\alpha_{inertia}$ values (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	-6630,52	962571,1	Significant
CopyBroker1	2595328	798563	
StandardBroker1	-4719916	1339802	Significant

In terms of the cash, the Copy Agent is clearly superior. For a further analysis we also need to look at the pick rates. We start with the pick rates for consumers. The pick rates of Households can be found in Table 6.18 and in Table A.34 in the Appendix. The pick rates of Offices and Factories can be found in Tables A.35, A.36, A.37 and A.38 in the Appendix.

Table 6.18: Pick rates of Households for a Scenario with mixed $\alpha_{inertia}$ values (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	9,95%	5,490316%	Significant
CopyBroker1	83,46667%	6,500022%	
StandardBroker1	6,583333%	5,278086%	Significant

The results of pick rates of consumers clearly show that the Copy Agent is the best performing Agent in terms of attracting customers. This is similar to the results we have seen before. To get a more complete view of the situation in this market, we need to analyze the pick rates of producers too. These pick rates can be found in Table 6.19 and in Table A.39 in the Appendix.

Table 6.19: Pick rates of Producers for a Scenario with mixed $\alpha_{inertia}$ values (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	4,071429	9,520344	Significant
CopyBroker1	45,22857	7,870106	
StandardBroker1	50,7	13,20237	Not significant

The Copy Agent did not manage to attract most of the producers, because the Standard Agent managed to attract most of them eventually. The results are similar to what we have seen before. The Copy Agent manages to attract most producers in the beginning of the game, but after a while these producers are attracted to the Standard Agent.

6.4 Summary & Discussion

6.4.1 Summary

To investigate the success of our agent we have created several scenarios to test its performance. We started by analyzing the influence of the rationality of customers. This proved that the Copy Agent is the best performing Agent in terms of cash and pick rates of consumers. For producers, the Copy Agent is better for irrational customers, while the Standard Agent is better for rational customers. In a Scenario with customers with different rationalities, the Copy Agent was also better in terms of cash and attracting customers, but it was not better in attracting producers. An analysis of the performance of the agents per timeslot showed that the Copy Agent is superior in terms of cash and consumer pick rates for all timeslots. It is also superior in attracting producers in the initial phases in the game, but near the end, the Standard Agent manages to attract most producers. In Scenarios in which the Copy Agent competed with either the Standard Agent or the Score Agent, the Copy agent was the best Agent in terms of cash and attracting customers, but it did not manage to attract more producers than the Standard Agent. The Copy Agent did manage to attract more producers than the Score Agent, but this might have been different if the simulation time was longer, because the Score Agent had most producers at the end of the game. The Score Agent did manage to outperform the Standard Agent on all aspects.

One of the most influential factors in the simulated games was the influence of the customer's Inertia. For both very inert, moderately inert and very inert customers, the Copy Agent was the best Agent in terms of cash and attracted consumers, but this was not the case for producers. The Copy Agent was superior for producers that were not inert or producers that were very inert, but for producers that were in the middle of that, it did not manage to attract most of the producers. There are several explanations for this. For customers that only analyzed their costs (and did not take Inertia into account), the Copy Agent had the ability to adjust its rates and therefore it could keep many producers. This adjustment was not possible for customers that were more inert, except for customers that were very inert. Very inert producers picked the Copy Agent in the beginning of the game and they did not alter their tariff after that. In order to analyze a more heterogeneous market, we eventually created customers with different preferences for Inertia. In this market, the Copy Agent was the most successful Agent in terms of cash and attracted consumers, but not in terms of attracted producers, since producers preferred the Standard Agent eventually.

For all scenarios, the Copy Agent is the best performing agent is terms of cash and the attracted amount of consumers. This is however not the case for attracting producers. Therefore the best scenario for our Copy Agent is a scenario in which the Copy Agent manages to attract most of the producers too. This is the case for a scenario with very irrational customers, as well as for a scenario with rational customers that are not influenced by their inertia or rational customers that are very inert.

6.4.2 Discussion

There are some scenarios that we have not investigated. Suppose that there are multiple Copy Agents on the market for example. In this case the Copy Agents would probably still be the most successful agents, but they might have a negative effect on the development of prices. Copy Agents copy the tariffs of other agents and when they copy tariffs of the other Copy Agents, the prices might decrease a lot, which is something that we can explain. As earlier explained in this chapter, the Copy Agent has a preference for attracting consumers. Because of this, the rates of consumption tariffs might decrease more than the rates of the production tariffs and this effect might be strengthened because the Copy Agents copy the cheap consumption tariffs of their competing Copy Agents and therefore the profit margins of the Copy Agents would probably decrease and it would probably also be more difficult for them to attract producers. This can be resolved by changing the imbalance thresholds or by giving a lower bound to the rates of the consumption tariffs. In that case the profit margins of Copy Agents would not decrease a lot.

We could have also tested a scenario in which there is a Copy Agent that only copies other tariffs, but it does not adjust them. This agent would have probably not been more successful than any of the other Agents, because the other Agents would have already published the tariffs that the agent copied and the tariffs of this new Copy Agent would not have been better than them, because these tariffs are not adjusted. An adjustment of the copied tariffs is thus necessary. When an agent that only copies tariffs adjusts its copied tariffs in the same way as the original Copy Agent does, then this agent could be as successful as the original Copy Agent, because the copying component is clearly the component that gives the Copy Agent the competitive advantage over the other agents. This however mainly applies to customers that are rational, since the quantity of tariffs is more important for irrational customers and an agent that only copies tariffs creates less tariffs than the original Copy Agent for example.

Another possible scenario is a scenario in which the balancing costs are very high. When that is the case, the Copy Agent would probably still have attracted most of the consumers, but it would have to pay high balancing costs that might have resulted in a negative cash flow. To resolve this, the high balancing costs could have been taken into account in the agent's tariff adjustment system. In this case, no consumption tariffs would have had rates that are lower than the variable balancing costs and all production tariffs would have had rates that are lower than the variable balancing costs. In this case the agent would have always bought energy at a cheaper price than the balancing costs (if the agent had producers) and it would have also sold energy at a level that was higher than the balancing costs, so that, even with imbalances, the agent would still make a profit. For low imbalances the consumption tariffs could be priced lower than the variable balancing costs, because in that case most energy would have been bought at a lower price than the imbalance costs (through its production tariffs), which still allows the agent to make a profit. For high imbalances, this should not be the case.

In Power TAC, the wholesale market also plays a vital role, since a lot of energy can be bought on this market. The costs of buying this energy should be lower than the revenue generated from selling this energy to customers through the agent's consumption tariffs. Therefore an estimation of the price of energy at each hour of a specific day has to be made. The consumption tariffs should not have lower rates than this estimation. By doing this, the agent would always be able to buy energy at a cheaper rate than at which it sells the energy.

In Power TAC the customers will eventually have more complex decision models. Currently, the Copy Agent orders competing tariffs by their rates when they create an ordered list of competing tariffs. When more customer models are used, a more complex ordering method is needed. We could for example try to make a model for each customer class. In this model we generate a utility for a specific customer class and this utility is based on the customer models in Power TAC. In this model tariffs that should be more attractive for a certain class of customers should have a higher utility. We can use these utilities to create a new ordered list of competing tariffs of a specific customer class. In adjusting these tariffs we can adjust more factors than just the rates. We could for example alter the amount of green energy used in the tariff by analyzing the preferences of the customer class of that tariff. We can thus use the ideas of this thesis in a more complex environment by adjusting some parts in the mechanism of our agent. These adjustments do not change the core idea of this thesis, which is that an agent should analyze its competitors' tariffs and it should use these tariffs in creating its own tariffs and the adjustment have to based on specific customer classes. The ideas of this thesis can simply be extended and therefore the mechanism used in this thesis can be used in more complex simulation environments when it is properly adjusted.

Chapter 7

Conclusion

7.1 Conclusion

In our thesis we wanted to create an good-performing agent for the energy market. To get an idea about this, we have reviewed relevant literature about this, which included electronic energy markets, energy tariffs, and strategies in TAC games. The literature review indicated that there was still much work to be done in the area of designing tariffs in a competitive market. We have thus focused our attention on these markets.

We wanted to use the Power TAC as a simulation environment for our agent, but due to the unsatisfactory performance of the server at several points of its development, we decided to create our own simulation environment based on Power TAC, which was more limited than Power TAC, but it did gave us more freedom in altering the parameters of the simulation environment (such as the rationality for example). We have used a simplified version of the customer choice model of Power TAC. This simplified version used the same logit choice model as Power TAC, but the utilities used in this model only analyzed the costs element and the inertia element, because we did not use agents that used the other components (risk and energy content) in designing their tariffs. The energy usages per customer are based on a method created by Kevin Meijer and these usages mainly depend on the time of the day and the class of the customer. Our distribution utility uses a simple method to generate fees for agents, because balancing is not the focus of this thesis and the wholesale market should be included for creating a good balancing method and we have not included this market, because we have focused on the tariff market.

Our Agent Framework consists of several elements. At first it has the possibility to classify tariffs using k-nearest neighbors. It also has methods to assign scores to tariffs based on the rates of the tariffs, the quantities transferred through the tariffs, and the variability of the tariffs. The actions made by the agent depend on specific imbalance scenarios, which should make sure that the agent stays reasonably balanced. Our agent also has the capability to analyze the tariffs of competitor brokers. Depending on the imbalance scenario, certain tariffs can be copied and altered. The tariffs that are copied are chosen on the basis of their class and their average class rate. Sometimes tariffs are not copied, because this could lead to an unprofitable situation (production tariffs with higher rates than consumption tariffs, for example). In the process of copying tariffs, the tariffs can be altered on the basis of the differences between the tariff's current rates and its rates in the past. For this, links between tariffs need to exist. If these links do not exist, we create them with a specific algorithm that is based on certain assumptions.

In our experiments we have used three types of agents: the Standard Agent, the Score Agent, and the Copy Agent. The Score Agent and Copy Agent are the only agents that utilize parts of our framework and the Copy Agent is the only agent that utilizes the copying mechanism that is described in our framework. We have performed experiments for scenarios with customers differing in their rationality and with customers with varying influences of inertia. In all scenarios, the Copy Agent was the best performing agent in terms of cash and the amount of attracted consumers. This was not the case for the amount of attracted producers. In scenarios with rational customers and in scenarios with rational customers and an influence of inertia that was moderate, the Standard Agent managed to attract most producers. The Copy Agent did manage to attract most producers for scenarios with a low rationality or scenarios with rational customers that were not inert or very inert. For irrational customers, the Copy Agent did well, because it published more tariffs than other Agents and therefore the Copy Agent had a higher change of being picked. For rational customers and very inert customers, the Copy Agent did well, because it attracted most producers in the beginning of the game and these producers did not change their tariff after that. For rational customers and customer that were not inert, the Copy Agent managed to keep most producers that it attracted in the beginning of the game and it could keep the rates of its production tariffs more competitively because agents switched tariffs easier and earlier and therefore the Copy Agent could take actions to improve these tariffs earlier.

7.2 Limitations

This thesis had several limitations. First we were not able to investigate the entire electricity market, because we have focused on the tariff market. The wholesale market is thus ignored in this thesis. We also did not analyze all tariff types and in future research, other type of tariffs, such as real-time pricing tariffs, could be taken into account as well. Our balancing mechanism is also quite simple and this method could be improved as well. The focus of this thesis was also on the economic part of the electricity market and not on the physical parts of this market. The amount of experiments was also limited and therefore we did not test a market with many agents, for example. We were also not able to test all of our parameters.

7.3 Discussion & future work

In this thesis we have described a framework that could perform well in a competitive energy market. There are however many directions for future research. An interesting future research topic is adding a strategy for the wholesale market to this framework, because this would make the agent complete and then the agent would be able to perform at the Power TAC competition. The interaction between the wholesale market and the tariff market could also be investigated. This would also make the tariff market more realistic, since the tariff market and the wholesale market are both an important part of electricity markets and several interactions between these markets exist. We can also investigate more advanced balancing mechanisms, which is something that can be combined with the investigation of including the wholesale market, because the wholesale market is an important way to balance the amount of energy.

Another research topic is to include learning elements in the framework of our thesis. Currently actions are taken on the basis of an imbalance scenario. It could be possible to create several scenarios by encoding these scenarios in states and for each state the best set of actions can be learned by using a specific learning algorithm. It could also be possible to improve the predictions of differences between tariffs by using a more complex prediction method than exponential smoothing.

Investigating this framework in a market with more agents is also interesting. It could even be more interesting when these agents have more diverse types of strategies. Investigating different parameter settings of our agent could be interesting too and this could be combined with investigations that have more type of agents, because some settings might perform better under these circumstances. It could also be interesting to develop more complex tariff types in combination with the framework of this thesis. We can also extend our framework with more advanced customer models. It could be interesting to create more specific methods to determine the success of tariffs for a specific customer created by these more advanced customer models. These methods can for example be used in ranking the tariffs of competitors in the copying mechanism of this framework.

Appendix A

Results of experiments

A.1 Different lambda values

Table A.1: Cash

λ	Broker	Average Amount of Cash	Standard Deviation	T-test
0	ScoreBroker1	693935,8	172634,6	Significant
	CopyBroker1	2212436	318196,1	
	StandardBroker1	-137218,6	93306,52	Significant
1	ScoreBroker1	642417,9	203850	Significant
	CopyBroker1	1999653	300917,9	
	StandardBroker1	-117240,1	98160,43	Significant
5	ScoreBroker1	301660,4	166144,3	Significant
	CopyBroker1	1788472	226859,5	
	StandardBroker1	-105010,4	121227	Significant
10	ScoreBroker1	-32156,58	315978,4	Significant
	CopyBroker1	1837992	260355,3	
	StandardBroker1	-152682,9	202123,7	Significant
25	ScoreBroker1	-375524,3	611142	Significant
	CopyBroker1	2260661	620713,7	
	StandardBroker1	-862276,9	947699,7	Significant
50	ScoreBroker1	87209,85	665466,3	Significant
	CopyBroker1	2040119	715207,8	
	StandardBroker1	-3269968	1949969	Significant
100	ScoreBroker1	198123,1	193326,4	Significant
	CopyBroker1	2246595	499917	
	StandardBroker1	-4864845	1126470	Significant
300	ScoreBroker1	235826,3	210080	Significant
	CopyBroker1	1980468	497942	
	StandardBroker1	-4883874	1758203	Significant
500	ScoreBroker1	471890	533459,4	Significant
	CopyBroker1	1684692	433504,9	
	StandardBroker1	-4867913	1032198	Significant
600	ScoreBroker1	160273,7	597636,8	Significant
	CopyBroker1	1726136	583071,5	
	StandardBroker1	-4811961	1010900	Significant

Table A.2: Pick rates of Producers

λ	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	26,8%	3,4205%	Significant
	CopyBroker1	60,08571%	3,9373%	
	StandardBroker1	6,714286%	1,235%	Significant
1	ScoreBroker1	25,65714%	2,3789%	Significant
	CopyBroker1	63,51429%	2,5506%	
	StandardBroker1	7,042857%	1,2887%	Significant
5	ScoreBroker1	19,87143%	3,3825%	Significant
	CopyBroker1	72,25714%	3,5065%	
	StandardBroker1	7,671429%	1,3151%	Significant
10	ScoreBroker1	18,37143%	3,5566%	Significant
	CopyBroker1	72,91429%	4,1171%	
	StandardBroker1	8,7%	2,2734%	Significant
25	ScoreBroker1	19,25714%	5,3528	Significant
	CopyBroker1	65,4%	7,6614%	
	StandardBroker1	15,34286%	8,0408%	Significant
50	ScoreBroker1	7,342857%	7,8532%	Significant
	CopyBroker1	55,02857%	10,43%	
	StandardBroker1	37,62857%	15,202%	Significant
100	ScoreBroker1	1,728571%	3,2051%	Significant
	CopyBroker1	42,92857%	9,8861	
	StandardBroker1	55,34286%	11,59%	Not Significant
300	ScoreBroker1	1,457143%	3,0645%	Significant
	CopyBroker1	41,87143%	15,219%	
	StandardBroker1	56,67143%	15,815%	Not Significant
500	ScoreBroker1	1,257143%	1,5932%	Significant
	CopyBroker1	42,18571%	9,1331%	
	StandardBroker1	56,55714%	9,4331%	Not Significant
600	ScoreBroker1	2,814286%	6,324%	Significant
	CopyBroker1	41,52857%	11,141%	
	StandardBroker1	55,65714%	12,295%	Not Significant

Table A.3: Pick rates of Households

λ	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	22,7%	3,22073%	Significant
	CopyBroker1	69,63333%	4,021725%	
	StandardBroker1	3,7%	1,042377%	Significant
1	ScoreBroker1	23,65%	2,86841%	Significant
	CopyBroker1	70,28333%	2,723678%	
	StandardBroker1	4,633333%	1,54806%	Significant
5	ScoreBroker1	20,06667%	2,974748%	Significant
	CopyBroker1	74,6%	3,403816%	
	StandardBroker1	5,316667%	1,407893%	Significant
10	ScoreBroker1	18,13333%	3,808885%	Significant
	CopyBroker1	76,01667%	3,993379%	
	StandardBroker1	5,85%	1,141841%	Significant
250	ScoreBroker1	17,01667%	4,697237%	Significant
	CopyBroker1	77,5%	4,987118%	
	StandardBroker1	5,483333%	2,004308%	Significant
50	ScoreBroker1	13,55%	10,50607%	Significant
	CopyBroker1	83,18333%	10,54895%	
	StandardBroker1	3,266667%	2,771197%	Significant
100	ScoreBroker1	8,45%	7,507715%	Significant
	CopyBroker1	88,75%	8,950726%	
	StandardBroker1	2,8%	2,518702%	Significant
300	ScoreBroker1	11,46667%	6,753297%	Significant
	CopyBroker1	84,95%	7,254984%	
	StandardBroker1	3,583333%	4,535597%	Significant
500	ScoreBroker1	16,76667%	12,11596%	Significant
	CopyBroker1	77,53333%	12,19069%	
	StandardBroker1	5,7%	11,4355%	Significant
600	ScoreBroker1	13,36667%	9,16062%	Significant
	CopyBroker1	84,6%	10,27493%	
	StandardBroker1	2,033333%	2,815787%	Significant

Table A.4: Pick rates of Offices

λ	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	22,175%	3,1131%	Significant
	CopyBroker1	70,625%	2,9284%	
	StandardBroker1	3,675%	1,2489%	Significant
1	ScoreBroker1	23,525%	3,5521%	Significant
	CopyBroker1	71%	3,724%	
	StandardBroker1	4,1%	0,9262%	Significant
5	ScoreBroker1	19,15%	3,7455%	Significant
	CopyBroker1	75,225%	4,5494%	
	StandardBroker1	5,6%	1,2835%	Significant
10	ScoreBroker1	17,475%	3,9084%	Significant
	CopyBroker1	76,55%	3,8385%	
	StandardBroker1	5,975%	1,6016%	Significant
25	ScoreBroker1	15,675%	5,3219%	Significant
	CopyBroker1	77%	5,2641%	
	StandardBroker1	7,325%	4,7636%	Significant
50	ScoreBroker1	11,475%	7,5733%	Significant
	CopyBroker1	83,175%	11,306%	
	StandardBroker1	5,35%	6,009%	Significant
100	ScoreBroker1	8,75%	4,9749%	Significant
	CopyBroker1	87,6%	8,1879%	
	StandardBroker1	3,65%	5,6268%	Significant
300	ScoreBroker1	10,525%	7,8026%	Significant
	CopyBroker1	86,775%	9,9835%	
	StandardBroker1	2,7%	6,1095%	Significant
500	ScoreBroker1	15,225%	11,306%	Significant
	CopyBroker1	81,95%	13,886%	
	StandardBroker1	2,825%	7,9988	Significant
600	ScoreBroker1	12,4%	10,001%	Significant
	CopyBroker1	82,7%5	10,34%	
	StandardBroker1	4,85%	7,1527%	Significant

Table A.5: Pick rates of Factories

λ	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	24%	6,958524%	Significant
0	CopyBroker1	68,3%	8,760558%	
0	StandardBroker1	3,3%	2,178846%	Significant
1	ScoreBroker1	23,1%	5,40857%	Significant
1	CopyBroker1	70,5%	6,77068%	
1	StandardBroker1	4,3%	2,451637%	Significant
5	ScoreBroker1	18,7%	5,921415%	Significant
5	CopyBroker1	75,4%	4,903275%	
5	StandardBroker1	5,9%	3,076225%	Significant
10	ScoreBroker1	15,7%	6,061961%	Significant
10	CopyBroker1	76,8%	7,000752%	
10	StandardBroker1	7,5%	4,045791%	Significant
25	ScoreBroker1	11,1 %	5,485867%	Significant
25	CopyBroker1	83,9%	8,717194%	
25	StandardBroker1	5%	7,525396%	Significant
50	ScoreBroker1	11,6%	16,28173%	Significant
50	CopyBroker1	83,5%	16,79442%	
50	StandardBroker1	4,9%	8,168618%	Significant
100	ScoreBroker1	7,5%	7,619228%	Significant
100	CopyBroker1	89,5%	8,101332%	
100	StandardBroker1	3%	5,448322%	Significant
300	ScoreBroker1	4,3%	4,31765%	Significant
300	CopyBroker1	85,5%	22,06092%	
300	StandardBroker1	10,2%	20,92493%	Significant
500	ScoreBroker1	8,3%	8,832357%	Significant
500	CopyBroker1	83,9 %	13,9091%	
500	StandardBroker1	7,8 %	12,25862%	Significant
600	ScoreBroker1	7,1 %	4,700504%	6Significant
600	CopyBroker1	87,7 %	14,64097%	
600	StandardBroker1	5,2%	7,352765%	Significant

A.2 Heterogeneous customers

Table A.6: Office pick rates for heterogeneous customers with superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	5,875%	4,016004%	Significant
CopyBroker1	91,75%	8,844415%	
StandardBroker1	2,375%	7,783037%	Significant

Table A.7: Office pick rates for heterogeneous customers with no superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	4,575%	3,265751%	Significant
CopyBroker1	93,575%	6,489414%	
StandardBroker1	1,85%	4,997631%	Significant

Table A.8: Factory pick rates for heterogeneous customers with superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	3%	3,866183%	Significant
CopyBroker1	88,5%	10,58052%	
StandardBroker1	8,5%	11,92741%	Significant

Table A.9: Factory pick rates for heterogeneous customers with no superseding tariffs

Broker	Average	Standard Deviation	T-test
ScoreBroker1	2,9%	3,918915%	Significant
CopyBroker1	91,9%	7,122241%	
StandardBroker1	5,2 %	7,824388%	Significant

A.3 Results per timeslot

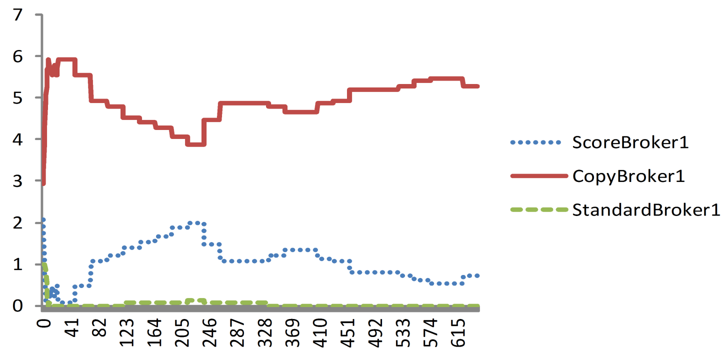

Figure A.1: Pick rates of households per timeslot

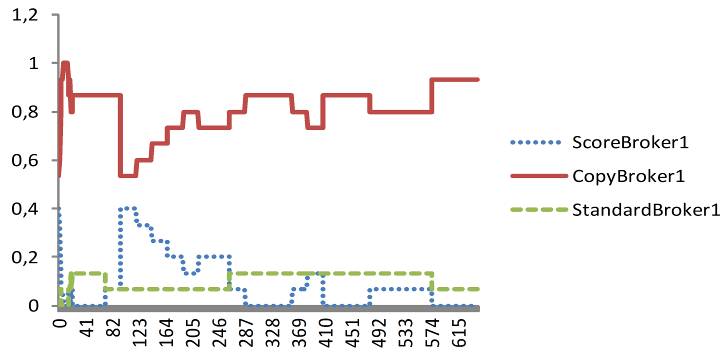

Figure A.2: Pick rates of factories per timeslot

A.4 Copy vs Standard Agent

Table A.10: Cash values of Scenario Copy vs Standard (no superseding)

Broker	Average	Standard Deviation	T-test
CopyBroker1	2849029	903014	
StandardBroker1	-4291448	1848823	Significant

Table A.11: Pick rates of households (non-superseding tariffs)

Broker	Average	Standard Deviation	T-test
CopyBroker1	94,1%	4,438139%	
StandardBroker1	5,883333%	4,435733%	Significant

Table A.12: Factory pick rates with superseding tariffs

Broker	Average	Standard Deviation	T-test
CopyBroker1	88,5%	16,27235%	
StandardBroker1	11,5%	16,27235%	Significant

Table A.13: Factory pick rates with no superseding tariffs

Broker	Average	Standard Deviation	T-test
CopyBroker1	87,3%	24,37665%	
StandardBroker1	12,7%	24,37665%	Significant

Table A.14: Office pick rates with superseding tariffs

Broker	Average	Standard Deviation	T-test
CopyBroker1	92,825%	20,19398%	
StandardBroker1	7,175%	20,19398%	Significant

Table A.15: Office pick rates with no superseding tariffs

Broker	Average	Standard Deviation	T-test
CopyBroker1	92,025%	22,13028%	
StandardBroker1	7,975%	22,13028%	Significant

Table A.16: Pick rates of producers (non-superseding tariffs)

Broker	Average	Standard Deviation	T-test
CopyBroker1	52,94286%	9,456146%	
StandardBroker1	47,05714%	9,456146%	Significant

A.5 Score Agent vs Standard Agent

Table A.17: Production pick rates of the Scenario Score Agent vs Standard Agent

Broker	Average	Standard Deviation	T-Test
ScoreBroker1	60,32857%	16,88255%	
StandardBroker1	39,67143%	16,88255%	Significant

Table A.18: Factory pick rates of the Scenario Score Agent vs Standard Agent

Broker	Average	Standard Deviation	T-Test
ScoreBroker1	66,3%	37,48558%	
StandardBroker1	33,7%	37,48558%	Significant

Table A.19: Office pick rates of the Scenario Score Agent vs Standard Agent

Broker	Average	Standard Deviation	T-Test
ScoreBroker1	66,975%	26,54662%	
StandardBroker1	33,025%	26,54662%	Significant

A.6 Copy Agent vs Standard Agent

Table A.20: Cash values for the Scenario Copy Agent vs Score Agent (without superseding tariffs)

Broker	Average	Standard Deviation	T-Test
ScoreBroker1	-2327110	1378443,44	Significant
CopyBroker1	3193663	1026828,673	

Table A.21: Office pick rates for the Scenario Copy Agent vs Score Agent (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	8,875%	7,303342782%	Significant
CopyBroker1	91,125%	7,303342782%	

Table A.22: Production pick rates for the Scenario Copy Agent vs Score Agent (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	37,85714%	11,27319187%	Significant
CopyBroker1	62,14286%	11,27319187%	

Table A.23: Production pick rates for the Scenario Copy Agent vs Score Agent (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	34,58571%	14,06368055%	Significant
CopyBroker1	65,41429%	14,06368055%	

Table A.24: Household pick rates for the Scenario Copy Agent vs Score Agent (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	18,25%	9,801464862%	Significant
CopyBroker1	81,75%	9,801464862%	

Table A.25: Household pick rates for the Scenario Copy Agent vs Score Agent (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	18,51667%	9,208739175%	Significant
CopyBroker1	81,48333%	9,208739175%	

Table A.26: Factory pick rates for the Scenario Copy Agent vs Score Agent (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	7,8%	9,105233%	Significant
CopyBroker1	92,2 %	9,105233%	

Table A.27: Factory pick rates for the Scenario Copy Agent vs Score Agent (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	4,2%	4,047091%	Significant
CopyBroker1	95,8%	4,047091%	

A.7 The influence of Inertia

Table A.28: Average cash values per $\alpha_{inertia}$

$\alpha_{inertia}$	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	-570321	470170,9	Significant
0	CopyBroker1	2223870	927778,8	
0	StandardBroker1	-740048	1111845	Significant
0,15	ScoreBroker1	-396964	1030398	Significant
0,15	CopyBroker1	2523757	1147734	
0,15	StandardBroker1	-4111641	2335012	Significant
0,3	ScoreBroker1	289,1681	498701,2	Significant
0,3	CopyBroker1	1959367	565775,3	
0,3	StandardBroker1	-4516095	2164504	Significant
0,5	ScoreBroker1	55899,66	132389,2	Significant
0,5	CopyBroker1	4363600	1029707	
0,5	StandardBroker1	284355,6	1412128	Significant

Table A.29: Average pick rates of Households per $\alpha_{inertia}$

$\alpha_{inertia}$	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	21,01667%	5,293132%	Significant
0	CopyBroker1	71,15%	5,926918%	
0	StandardBroker1	7,833333%	2,073221%	Significant
0,15	ScoreBroker1	11,98333%	6,805979%	Significant
0,15	CopyBroker1	83,31667%	8,930842%	
0,15	StandardBroker1	4,65%	6,285112%	Significant
0,3	ScoreBroker1	8,983333%	4,786036 %	Significant
0,3	CopyBroker1	80,65%	9,89032%	
0,3	StandardBroker1	10,33333%	9,094694%	Significant
0,5	ScoreBroker1	2,8%	1,801234%	Significant
0,5	CopyBroker1	82,65 %	12,96936%	
0,5	StandardBroker1	14,48333%	12,76484%	Significant

Table A.30: Average pick rates of Offices per $\alpha_{inertia}$

$\alpha_{inertia}$	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	10,8%	5,967897%	Significant
0	CopyBroker1	81%	6,949063%	
0	StandardBroker1	8,2%	3,657724%	Significant
0,15	ScoreBroker1	10,8%	5,967897%	Significant
0,15	CopyBroker1	91,75%	8,844415%	
0,15	StandardBroker1	2,375%	7,783037%	Significant
0,3	ScoreBroker1	5,475%	3,618211%	Significant
0,3	CopyBroker1	87,7%	16,59772%	
0,3	StandardBroker1	6,825%	15,95328%	Significant
0,5	ScoreBroker1	3,3%	4,105196 %	Significant
0,5	CopyBroker1	85,45%	14,96302%	
0,5	StandardBroker1	11,25%	15,12013%	Significant

Table A.31: Average pick rates of Factories per $\alpha_{inertia}$

$\alpha_{inertia}$	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	1,6%	1,667018%	Significant
0	CopyBroker1	83,9%	8,765362%	
0	StandardBroker1	14,5%	8,357159%	Significant
0,15	ScoreBroker1	56%	3,866183%	Significant
0,15	CopyBroker1	3%	10,58052%	
0,15	StandardBroker1	8,5%	11,92741%	Significant
0,3	ScoreBroker1	2,8%	4,873127%	Significant
0,3	CopyBroker1	77,2%	30,25088%	
0,3	StandardBroker1	20%	31,7689%	Significant
0,5	ScoreBroker1	3,6%	3,015748%	Significant
0,5	CopyBroker1	81,8%	35,35028%	
0,5	StandardBroker1	14,6%	35,6893%	Significant

Table A.32: Average pick rates of Producers per $\alpha_{inertia}$

$\alpha_{inertia}$	Broker	Average	Standard Deviation	T-Test
0	ScoreBroker1	16%	4,166255%	Significant
0	CopyBroker1	68,27143%	11,7509%	
0	StandardBroker1	15,72857%	10,92833%	Significant
0,15	ScoreBroker1	8%	12,165%	Significant
0,15	CopyBroker1	44,05714%	9,51119%	
0,15	StandardBroker1	47,94286%	18,9944%	Not significant
0,3	ScoreBroker1	3,557143%	6,644235%	Significant
0,3	CopyBroker1	44,98571%	11,42424%	
0,3	StandardBroker1	51,45714%	15,63628%	Not significant
0,5	ScoreBroker1	0,042857%	0,191663%	Significant
0,5	CopyBroker1	88,25714%	23,36998%	
0,5	StandardBroker1	9,542857%	23,33346%	Significant

A.8 Mixed values for $\alpha_{inertia}$

Table A.33: Cash values for a Scenario with mixed $\alpha_{inertia}$ values (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	-101883	389682,4	Significant
CopyBroker1	3004159	780892	
StandardBroker1	-4631452	1158517	Significant

Table A.34: Pick rates of Households for a Scenario with mixed $\alpha_{inertia}$ values (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	8,3%	5,484588%	Significant
CopyBroker1	82,13333%	9,453735%	
StandardBroker1	9,566667%	5,987414%	Significant

Table A.35: Pick rates of Offices for a Scenario with mixed $\alpha_{inertia}$ values (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	9,1%	9,934787%	Significant
CopyBroker1	90,125%	10,34519%	
StandardBroker1	0,775%	1,12945%	Significant

Table A.36: Pick rates of Offices for a Scenario with mixed $\alpha_{inertia}$ values (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	4,575%	5,410212%	Significant
CopyBroker1	93,825%	6,712665%	
StandardBroker1	1,6%	2,562893%	Significant

Table A.37: Pick rates of Factories for a Scenario with mixed $\alpha_{inertia}$ values (superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	3%	3,077935%	Significant
CopyBroker1	94,3%	8,736493%	
StandardBroker1	2,7%	8,11172%	Significant

Table A.38: Pick rates of Factories for a Scenario with mixed $\alpha_{inertia}$ values (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	2,3%	2,178846%	Significant
CopyBroker1	95,2%	5,366563%	
StandardBroker1	2,5%	4,673554%	Significant

Table A.39: Pick rates of Producers for a Scenario with mixed $\alpha_{inertia}$ values (without superseding tariffs)

Broker	Average	Standard Deviation	T-test
ScoreBroker1	3,242857%	4,764057%	Significant
CopyBroker1	43,28571%	6,61249%	
StandardBroker1	53,47143%	9,032356%	Significant

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