Erasmus University Rotterdam

Erasmus School of Economics

Master Thesis [program Economics of Markets and Organizations]

Empirical Evidence Against Edgeworth Cycles in the German Retail Gasoline Market

Name of Student: Benjamin Boesch
Student Number: 620666

Supervisor: Prof. Sacha Kapoor
Second Reader: Prof. Dana Sisak

Statement of Academic Integrity

I hereby declare that this Master's thesis is the result of my own independent work and research, except where otherwise acknowledged.

Benjamin J.J. Boesch, 25.03.2023

Abstract

The pricing pattern in the German retail gasoline market between firms is characterized by strong price increases that in turn are followed by incremental price cuts. Such price in and decreases, also referred to as price cycles in the literature, occur multiple times within a day and are likely to decrease consumer welfare. While collusive behavior may be one answer as to how such patterns come about, the theoretical literature has put forward other equilibrium concepts that may offer a convenient excuse. The question therefore arises if these alternative equilibria are applicable to the German market, and if they are consistent with the behavior of the firms in said market, or if collusion indeed seems to be the only valid explanation.

To answer this question, I divide my analysis into two parts. In the first part, I examine the theoretical models that are most frequently used to describe price cycles and apply them in the context of the German retail gasoline market. The main goal of this part of the analysis is to determine if one can exclude these alternatives, i.e. non-collusive equilibrium concepts, a priori due to the ramifications of the German market.

In the second part of the analysis, I examine the average prices by brand in the retail gasoline market in Hamburg, Germany. Specifically, I aim to look at deviations from the predominant pricing patterns, to identify breaches of possibly collusive agreements. Furthermore, I look at the timing and consistency of the pricing patterns within weeks to identify inconsistencies with non-collusive equilibria, most of which require mixed strategy and the absence of focal points.

In a nutshell, the first part of the analysis focuses on if in theory German retail gasoline market allows for price cycles that are sustained by non-collusive equilibria. The second part examines if the behavior of firms in the market is consistent with what the theory on such equilibria suggests.

1. Introduction

As is the case in other retail gasoline markets such as in Australia (Byrne & DeRoos, 2019), and other countries around the world (Eckert, 20123), the retail gasoline market in Germany exhibits cyclical price patterns (Linder, 2018), (Cabral et Al., 2018). Such patterns are characterized by strong price increases that are followed by incremental underbidding among competitors (Eckert, 2013). These patterns are usually repeated, resulting in a cyclical, wave like pattern. The pricing cycles in the German gasoline market occur multiple times throughout the day which makes it unlikely that price in- and decreases are a reaction to changes in the cost of gasoline, leading to the assumption that cyclical prices do incur some degree of consumer welfare loss due to elevated prices (Cabral et Al., 2018).

Two of the most common equilibrium concepts the literature suggests being behind cyclical pricing behavior in retail gasoline markets are the standard collusive equilibrium and the Markov Perfect Equilibrium (Noel, 2008). While both equilibrium concepts in theory result in prices above the competitive level and thus incur losses to consumer welfare, they differ considerably in the mechanisms that ensure their stability (Maskin & Tirole, 1988). Actions in a collusive agreement by themselves are not best responses, there needs to be some kind of explicit or implicit agreement between players to cooperate, which in turn is upheld by threats of returning to less profitable equilibria in case of deviation (Tadelis, 2013). In contrast, actions in a Markov Perfect Equilibria are in and by themselves stable best responses that do not need a cooperative agreement between players (Maskin & Tirole, 1988). It should therefore come as no surprise that pricing cycles sustained by equilibria that do not require cooperative agreements could offer a convenient excuse for firms in the German retail gasoline market. I therefore formulate my research question and hypotheses as follows:

Research Question: Are the cyclical price increases in the German retail gasoline market collusive, or could they be the result of other, non-collusive equilibria?

H0: *Non-collusive equilibria cannot be excluded as a valid explanation for the pricing cycles in the German retail gasoline market.*

HA: *Pricing Cycles in the German retail gasoline market are sustained by collusive equilibria*

One of the main challenges in differentiating between the two equilibrium concepts lies in the idea that the shape of the pricing cycles can look identical. For instance, Byrne & DeRoos (2019) find evidence for cyclical pricing patterns that are sustained by collusive agreements.

However, the shape of these patterns could almost serve as a textbook real-life examples of pricing cycles sustained by Markov Perfect Equilibrium. Byrne & DeRoos can reject the possibility of these price cycles to be sustained by a Markov Perfect Equilibrium a priori due to a mandated simultaneity in pricing decisions in the Australian retail gasoline market. While collusive agreements can be created from a range of repeated games according to the folk theorem (Tadelis, 2013), pricing cycles sustained by Markov Perfect Equilibria are less flexible and require a range of assumptions to hold (Maskin & Tirole, 1988). Furthermore, there is a number of actions, such as punishments, or the use of focal points that are inconsistent with Markov Perfect Equilibria.

To test the alternative hypothesis, that is, collusion being responsible for the pricing patterns in the German retail gasoline market, I structure my analysis into two parts: In the first part, I examine the theoretical literature on the equilibria behind price cycles. The goal thereof is to determine if the retail gasoline market in Germany allows for the possibility pricing cycles that are sustained equilibria that do not require collusive agreements, henceforth referred to as Edgeworth cycles. To avoid a false a priori rejection of the null hypothesis I analyze the literature on more robust extensions of the Maskin & Tirole model, such as Noel (2008) which offer a better fit for the German market. Furthermore, to account for the finite nature of intraday interactions I supplement my analysis with two models of my own.

In the second part of the analysis, if I am unable to exclude non-collusive equilibria a priori, I examine if the behavior of firms in the market is consistent with non-collusive behavior as discussed in the first part. While the shape of price cycles is not unique to either equilibrium concept, there is a range of actions that may exclude Markov Perfect Equilibria and other non-collusive equilibria, such as a high consistency in pricing patterns as well as punishments for deviating from patterns. I observe the pricing patterns of the three largest brands in the retail gasoline market in Hamburg, Germany from 2015 to 2019. The dataset for my descriptive analysis is provided by Tankerkoenig.de, a price transparency website for the retail gasoline market that offers open access to historical pricing data on the retail gasoline market. To capture the brand- pricing interactions between retail gasoline firms I create a new dataset for each of my observational periods that contains the price of every gasoline station in Hamburg each minute. The minutely pricing data is subsequently used to create the conditional mean with respect to the brands in the market. As the computational effort for observing an entire week is quite considerable, I employ a half- interval search to find structural breaks in the pricing patterns in the market, thus decreasing the number of observed weeks required for my analysis.

In addition to observing the changes in the pricing patterns in the market, I analyze the timing and repetitiveness of the patterns to better determine the equilibrium concept sustaining the pricing cycles.

In the theoretical analysis of this thesis, I find that I cannot exclude the possibility of a non-collusive equilibrium sustaining pricing cycles in Germany. While the standard model of Maskin & Tirole considers only duopoly markets set in an infinite time horizon, several extensions to the baseline model such as Noel (2008) increase the applicability of the model to oligopoly markets with imperfect product substitutability. Furthermore, by extending the model of Maskin & Tirole to a finite setting, I find that the daily horizon of firm interactions in the German market is not mutually exclusive with non-collusive equilibria.

One of the main challenges of non-collusive price cycles lies in the public goods dilemma of which player is the first to increase prices (Maskin & Tirole, 1985). While a price increase is beneficial is for all players involved, players prefer for their counterpart to lead the way, resulting in a waiting game (Maskin & Tirole, 1985). I find that by introducing a final period to the game, waiting for the other player to increase prices incurs a penalty. Should the sequence of players be fixed, the penultimate player can coerce the opponent through subgame perfection into increasing prices. Should the sequence of players not be fixed on the other hand, the penalty incurred through waiting allows for a mixed strategy equilibrium in which players are indifferent between increasing prices and waiting for the other player to do so. The equilibrium differs from Maskin & Tirole (1985) in that it does not require discounting factors. While the equilibria in the finite setting may not be Markov Perfect Equilibria, they are non-collusive. I therefore cannot exclude the possibility of non-collusive equilibria in the German market on the grounds of finite, within day interactions between firms.

In the descriptive analysis of this thesis, I bifurcate the pricing cycles into those that happen during the night and those that happen during the day. This division has previously been employed by Cabral et Al. (2019). I document the breakdown of price cycles during the nighttime due to a deviation by one of the competitors in the market and subsequent punishment by the agents in the market. The ensuing unwillingness of the other competitors to follow the attempts of reintroducing the price cycles by one of the competitors suggests that cooperative agreements were indeed at play.

While the pricing cycles during the day seem unaffected by their nighttime counterparts, I observe a high degree of consistency in the timing and occurrence of the former. The implications thereof are twofold: Given that price increases occur at specific points in time each day, e.g. 12 pm, 2pm, one can deduce that these increases are indeed coordinated at focal points. Focal points are, however, a violation of a key assumption of Markov Perfect Equilibria, in that they indicate that it is not only the current state that influences the behavior of players, but also actions that reach further back in time that are being considered by the players. Additionally, by occurring consistently, price increases in the German market are unlikely to be coordinated with mixed strategies, which are a prerequisite for non-collusive agreements to circumvent the public goods dilemma according to Maskin & Tirole.

Therefore, while the retail gasoline market in Germany at least in theory may allow for price cycles sustained by non-collusive agreements, the behavior of the firms in the market points towards price cycles coordinated through collusive behavior.

The findings of the thesis contribute to the existing literature in two ways. First, the models included in this thesis extend the Edgeworth Cycle model of Maskin & Tirole into a finite setting. To the best of my knowledge, there does not exist a model so far that addresses the first mover public good issue in a finite setting with the use of a semi-sequential setup. Second, by examining the theoretical differences between collusive and non-collusive pricing cycles, this thesis points out inconsistencies with the behavior of the competitors in the German retail gasoline market and Markov Perfect Equilibria.

2. Literature Review

The retail gasoline market is frequently featured in the literature of industrial organization with over 75 articles published in academic journals on the topic according to Eckert (2013). Eckert (2013) further argues that one of the reasons thereof is antitrust scrutiny, with gasoline markets often being in the spotlight of competitive authorities. Literature on the retail gasoline market frequently cites the homogeneity of the commodity[1] as one of the key features which make the market ideal for research into oligopoly firm behavior (Eckert, 2013). Said absence of product differentiation on the commodity level allows researchers to isolate other economic factors of interest. For instance, Pennersdorfer et Al. (2020) analyze the effect of consumer information on price discrimination, using commuters, which do not occur additional search costs as a

[1] While the commodity itself is homogenous (Eckert, 2013), this does not necessarily extend to other factors in the retail market it is offered in, e.g. the physical distance between gasoline stations.

proxy for informed customers. Haucap et Al. (2015) use the homogeneity of the product by itself to analyze the effect of other dimensions of product differentiations, such as the distance between competitors and the effect on prices. Byrne and DeRoos (2016) utilize the homogeneity of gasoline as well as the simultaneity in pricing decisions to support their claim of implicit collusion in the Australian retail gasoline markets.

Eckert (2011) argues that the growing literature on cyclical pricing patterns in the gasoline market dates back as far as 1993 to Castanias and Johnson (1993), who find evidence for asymmetric cyclical patterns in the city of Los Angeles in the late 1960s. Research in other gasoline market asserts that pricing behavior resembling Edgeworth cycles (cyclical pricing patterns) has occurred in Germany (Bantle, 2018) as well as Australia (Wang, 2008), (Byrne & DeRoos, 2016) among others.

Maskin and Tirole (1988) are credited with laying the theoretical foundation for non-collusive cyclical behavior in sequential markets, first described by their namesake Edgeworth (1925). According to Maskin Tirole (1988) these pricing patterns in oligopoly markets exhibit strong price jumps followed by incremental underbidding phases, hence their asymmetry. While such cyclical behavior leads to prices that are above a competitive level, Maskin and Tirole (1988) argue that such pricing behavior in markets with homogenous goods does not require collusive agreements[2]. Instead, they claim that Edgeworth cycles are consistent by themselves referring to their earlier work on Markov Perfect Equilibria (Maskin & Tirole, 1988). These findings provide an alternative explanation to elevated simultaneous pricing in Bertrand oligopoly markets with homogenous goods and costs, which without the presence of collusive multi game agreements result in competitive prices, despite the limited number of competitors. (Ivaldi et Al., 2003) To make a distinction between collusive and non-collusive pricing cycles, pricing cycles sustained by non-collusive equilibria such as MPE[3] are referred to as Edgeworth Cycles for the rest of this thesis. Collusive pricing cycles are referred to as such.

For Markov Perfect Equilibria to be established, conditions such as sequential pricing must be met (Maskin & Tirole). Gasoline markets around the world differ with respect to the regulation imposed on their pricing behavior (Linder, 2018). For instance, retail gasoline markets in Germany are not restricted in the number of times they can raise prices throughout the day

---

[2] For a more thorough review of collusive agreements see Ivaldi et Al. (2003)

[3] i.e. Markov Perfect Equilibria

(Linder, 2018). In Austria, gasoline stations are not restricted in the number of price cuts, however prices can only be raised once a day. (Legal Information Service of Austria, 2011)

The Australian gasoline market is of particular interest to researchers such as Wang (2008) who analyzes the effect of a law that decrees gasoline stations to change their prices simultaneously, once a day, from an unlimited number of price changes not constrained to simultaneity. While it is the intent of the legislation to obstruct the stability of Edgeworth cycles and increase price transparency (stations are also required to upload the price changes to consumer websites), Byrne and DeRoos (2016) argue that the latter effect contributes not only to the stability but also the coordination and thus creation of implicit collusive equilibria. Byrne and DeRoos show that due to increased saliency, BP the market leader in Perth, Australia is able to coordinate weekly price jumps by sending price signals on the previous day. Notably, the shape of the pattern described by Byrne and DeRoos exhibits features of Edgeworth cycle behavior, despite the simultaneity of the pricing decisions which is mutually exclusive with Edgeworth cycles in the sense of Maskin and Tirole. Therefore, contrary to Wang (2008), Byrne and DeRoos do not classify their findings as Edgeworth cycle behavior but argue that due to the simultaneity of pricing decisions in the Australian market it follows that the behavior is sustained by collusive agreements.

As previously mentioned, the German gasoline stations are not restricted in the number of price changes in a day, be they positive or negative. Neither are stations required to price simultaneously. However, price changes by individual stations need to be reported to the office of market transparency shortly after they occur. Said data is available to websites such as Tankerkoenig.de or the German Automobile club which provide current pricing data on the universe of gasoline stations in Germany (German Ministry of Justice). While it is the primary goal of these regulations to increase consumer transparency, said legislation, as is the case in Australia (Byrne & DeRoos, 2016) also allows for increased price transparency between firms (Assad et Al., 2020).

The relatively liberal pricing regulations in the German market thus allow for, but are not restricted to, simultaneity. Stations can react to price decisions set by their competitors and vice versa, resulting in a market that may more closely resemble a sequential game, with reaction times between firms as proxies for commitment periods (Linder, 2018). Therefore, the literature on the cause of the cyclical pricing pattern in the German market is not entirely clear. Linder (2018) finds that patterns resembling Edgeworth cycles are prevalent in the German gasoline market between 2013 and 2015. Linder argues however that it cannot be determined whether these cycles represent a Markov Perfect Equilibrium or a collusive equilibrium due to the asymmetry of the cycles alone. Linder argues that simultaneous price jumps before a period of price setting inactivity in the evenings hint towards collusive behavior but contends that more theoretical research is necessary to definitively assign any equilibrium concept to the pricing cycles in Germany. DeHaas (2019) argues that the German gasoline market does not exhibit Edgeworth cycle behavior due to a decreased response to cost shocks in the market, measured by obstructions in the oil supply due to low water levels in the Rhine River.

Cabral et Al. (2018) document a change in the daily price cycles in the German gasoline market starting in the summer of 2015. Cabral et Al. argue that the emergence of an additional intra-day price cycle resulted due to a price matching guarantee initiated by one of the firms in the market, Shell which increased the incentive for its competitors to participate in the price spike. The proposed mechanism behind the price matching guarantee, however, builds upon the standard model of collusive agreements and assumes simultaneity in pricing decisions. Cabral et Al. conclude Edgeworth cycles interrupted by collusive price spikes to be the predominant pattern on the German market. However, Cabral et Al. do not disprove the existence of non-collusive equilibria as a possible alternative explanation for the emergence of the price spike.

While differentiating between tacit collusion and Edgeworth cycles may be irrelevant for immediate consumer welfare, the implications thereof may differ. For instance, Edgeworth cycles are constrained to strategic reactions that optimize firm profits in the immediate future (Maskin & Tirole, 1988). In an Edgeworth setting, a price jump of one firm will be followed by an incremental price reduction of its competitor (Maskin & Tirole). Collusive agreements on the other hand are not constrained by these sets of actions as the set of strategies need not be the best response to the current actions of the competitor (Tadelis, 2013).

Furthermore, Edgeworth cycles may be accompanied by challenges with respect to antitrust policies. Byrne and DeRoos (2016) point out the potential blind spot of antitrust legislature towards implicit collusion due to the lack of an explicit agreement. Should antitrust policy increasingly target implicit collusion the question arises if measures that target implicit collusion will be equally effective on Edgeworth cycles. On the flipside, non-collusive Equilibria such as Markov Perfect Equilibria could serve as a convenient disguise for collusive behavior in markets such as the retail Gasoline market in Germany.

This thesis contributes to the existing literature by analyzing the mechanisms behind pricing cycles sustained by Markov Perfect Equilibria put forward by Maskin & Tirole (1985) and applying these mechanisms to a novel model that takes into consideration the particularities of the German market. By laying the focus on disproving non-collusive equilibria, both theoretically and empirically, this thesis aims to further contribute to the claim of collusive behavior being the sustaining equilibrium concept behind the pricing patterns of the German retail gasoline market put forward by Linder (2019), Cabral et Al. (2019) and DeHaas (2019).

3. Theory on Pricing Behavior in Oligopoly Markets

3.1 Collusive Agreements

The literature on industrial organization focuses on a wide array of market equilibria, with Cournot and Bertrand competition forming the benchmark for oligopoly behavior. One outcome of markets in which players use prices as strategic variables is the Bertrand paradox, a market equilibrium in which both players set prices which are only marginally above or at the competitive level. Such an outcome, however, requires product homogeneity and symmetric costs among players. Product differentiation, which in the context of the gasoline market can be seen as the distance between gasoline stations (Pennersdorfer et Al.) generally decreases cross price elasticity and thus competition in a market. Asymmetrical costs in a market with homogenous goods may lead to the firm with lower costs setting their price below the marginal costs of the competitor. The latter result however may not translate to a market with product differentiation due to reduced cross price elasticity. The firm with the higher cost may still participate in the market, should the transportation costs for consumers outweigh the difference in cost and thus price between competitors (Ivaldi et Al.).

Generally speaking, however, in benchmark models on oligopoly behavior such as Cournot or Bertrand competition, prices do not reach a monopoly level. This builds from the idea that while monopoly prices set by both competitors would maximize profits, such outcomes generally do not constitute Nash Equilibria due to at least one party having an incentive to deviate (Tadelis, 2013). While monopoly prices in oligopoly markets may be infeasible for the models in the short run, the theory on collusive behavior uses the mechanism of super game agreements to explain why some firms in oligopoly markets engage in prices at elevated levels (Ivaldi et Al., 2003). Such super game agreements allow for both players to enter agreements on setting monopoly prices that, if broken once will induce either player to engage in a more competitive pricing strategy for the remaining iterations of the pricing game (Tadelis, 2013). In short, it is the threat of returning to less profitable but stable equilibria that is used to deter the other player from deviating from a less stable but more profitable pricing (Tadelis, 2013).

Therefore, to avoid confusion, I refer to a pattern as collusive behavior if and only if multi game agreements are being used by players to stabilize such profitable outcomes which only exist due to such agreements. I derive this definition from the Cambridge dictionary which lists collusion as an

"*Agreement between people to act together secretly or illegally in order to deceive or cheat someone.*"

Conversely, I will refer to price cycles as Edgeworth cycles if and only if they are assumed to be sustained by non-collusive equilibria. I derive this nomenclature from the work of Maskin & Tirole (1988) on non-collusive pricing cycles which they refer to as Edgeworth cycles.

Byrne and DeRoos (2016) point out the importance of the difference between explicit and implicit collusion in their study on the Australian retail gasoline market. While the agreements may be the same, e.g. setting monopoly prices for a specific good, explicit and implicit collusion differ in the mode of communication used to coordinate such agreements. (Byrne & DeRoos, 2019)

While explicit collusion is coordinated with the help of explicit communication e.g. verbal agreements on prices, such obvious communication is absent in implicit collusion. Instead, parties engaging in implicit collusion rely on price signals at focal points i.e. points of increased saliency. One example of such an implicit agreement is documented by Byrne and DeRoos in the Australian retail gasoline market in Perth. Prices in the market are determined simultaneously each day, which in theory should lead to competitive or near competitive gasoline prices. BP, one of the competitors in the market circumvents said situation by sending pricing signals each Wednesday by slightly increasing prices. Said signals are then followed by price increases to the monopoly level the following day. Byrne and DeRoos argue that by constantly repeating this pattern, BP manages to coordinate a collusive pricing pattern with its competitors making the use of an explicit agreement obsolete. (Byrne & DeRoos, 2019)

It should be reiterated at this point that the form of communication does not change the equilibrium concept behind the collusive agreements. Despite a more subtle coordination, the underlying mechanism of implicit collusion does not differ from explicit collusion. In both cases, players pick strategies that are not stable by themselves, but are enforced through the threat of returning to a less profitable equilibrium. (Byrne & DeRoos) Therefore, implicit agreements differ from Markov Perfect Equilibria, in that Markov Perfect Equilibria are stable by themselves and do not require any agreement be it explicit or implicit (Maskin & Tirole).

3.2 Markov Perfect Equilibria

The theory on oligopoly behavior in most cases thus far suggests that without collusive agreements, equilibrium prices in the market are below the monopoly level. Perhaps one of the most extreme instances of such strategic dilemma[4] is the Bertrand Paradox which suggests that in a market of homogenous goods and symmetric costs, prices will be at the competitive level. (Ivaldi et Al.) The literature covered in the previous section would thus suggest that prices above the equilibrium level, in this case cost level, must be sustained by collusive agreements.

Maskin and Tirole suggest an alternative equilibrium concept leading to pricing patterns above the Bertrand level, that does not involve collusive agreements to be made in the first place. Set in sequential and infinitely repeated games, i.e. players taking turns in playing their actions, Markov Perfect Equilibria are equilibria in which players optimize their strategies only in response to actions that are directly payoff relevant. Players use the information about the expected strategy of the competitor (and themselves) as well the action that has just been played by said competitor[5] to determine their optimal strategy with respect to present and expected future payoff[6]. (Maskin & Tirole)

In one example of such a Markov Perfect Equilibrium, Maskin and Tirole propose a market in which two firms compete in selling a homogenous good for an infinite number of periods. The firms get to choose their prices sequentially and must therefore commit to set prices for two periods, consumers have an infinitely high cross-price elasticity, meaning that all customers prefer buying at the cheapest option. Said elasticity is borne to the homogeneity of the good that is provided. As a result, being underbid by the competitor as well as selling products at a competitive price leads to profits of zero[7]. Should one firm (Firm 1) initiate a price jump, i.e. raise its prices, the other firm (Firm 2) will no longer be indifferent between a price jump and competitive price, but will instead choose to incrementally underbid Firm 1, gaining the entire market profit for one period. In turn, Firm 1 will underbid the price just set by Firm 2 and so

---

[4] From the perspective of firms in the market

[5] Note that the previous action being payoff relevant is due to sequentialty. Players have to commit to their actions for two periods, e.g. the (pricing) action set by the first player in the first period will remain in period two when the second player can decide on his or her action. (Maskin & Tirole)

[6] For a formal definition, see Maskin, E., & Tirole, J. (1988). A theory of dynamic oligopoly, I: Overview and quantity competition with large fixed costs, pp. 554

[7] Both assumptions are frequently commonplace in the literature on homogenous goods markets. Concerns about the applicability of such assumptions will be adressed in the following section.

on. While the undercutting phase is profitable for both firms in the market, the profit for the firm that initiates the price jump, gets a lower profit than the firm that freerides on the price jump as the free rider or follower is the first to underbid its rival at a level above the competitive price. This results public good dilemma, as both firms would profit from an undercutting phase, but each firm waits for the other to initiate a price jump. (Maskin & Tirole, 1988)

Maskin & Tirole (1988) circumvent this dilemma by introducing a discount factor that through the mechanism of opportunity cost punishes waiting for the other firm to initiate a price jump. The discounting factor can be set as such that it satisfies a symmetric equilibrium in mixed strategies, where firms are indifferent between raising prices and remaining at the competitive level, and thus able to randomize between strategies. Maskin & Tirole (1988) create a pair of symmetric reaction functions that optimize future payoff by proving the possible existence of a price $\underline{p}$ at which firms prefer to set their prices to a zero-profit level p_C. At that level, firms will be indifferent between raising prices to one increment k above the price $\overline{p}$ that maximizes the payoff of the undercutting phase, i.e., $\overline{p} + k$, which makes firm lower their prices to p_C in the first place. Between $\overline{p} + k$ firms underbid each other incrementally until they again arrive at $\underline{p}$, thus closing the cycle. Maskin & Tirole (1988) define these stages of the cycle as follows:

Price jump*: One firm raises its price to* $\overline{p} + k$.

Undercutting phase*: The other firm underbids the price jump of the initiator, leading the firms to take turns in underbidding one another until they reach* $\underline{p}$

Price war phase: *After reaching the competitive price level, firms randomize between initiating a price jump and remaining at the competitive price level.*

The following definitions of Maskin & Tirole (1988) will remain unchanged for the rest of this thesis. Given that price jumps are much greater in absolute size than price cuts (price decreases) , Edgeworth cycles in the sense of Maskin & Tirole (1988) exhibit an asymmetric pattern, as can be seen in Figure 1. However, asymmetry alone does not guarantee that a pricing cycle is sustained by a Markov Perfect Equilibrium. (Linder, 2018) For instance, Byrne and DeRoos (2016) give convincing evidence for asymmetric price cycles being sustained by a collusive equilibrium, not a Markov Perfect Equilibrium.

The main difference between the two equilibrium concepts being the absence multi-game agreements in a Markov Perfect Equilibrium. While in collusive behavior, deviation from the collusive agreement is being deterred by the threat of punishment in future periods, Markov Perfect Equilibria are consistent in and by themselves. (Maskin & Tirole, 1988))

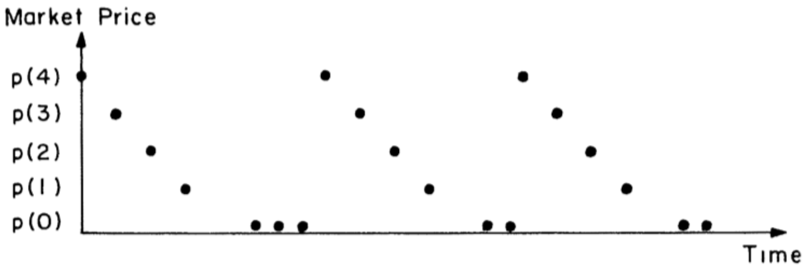

FIGURE 1.—Edgeworth cycles.

Figure 1: Depiction of Edgeworth cycle behavior. Prices are on the vertical, time on the horizontal axis. Dots represent the pricing decisions of the players. Note the variation in pricing decisions at the bottom of the vertical axis, which depict the randomness of the price war phase. Source: Maskin & Tirole (1988)

Many of the assumptions that are required for Markov Perfect Equilibria seem unrealistic in the real world. Even markets such as the gasoline market, whose commodity by itself is homogenous exhibit horizontal product differentiation due to spatial differences (Pennersdorfer et Al.). However, one of the key features of the Edgeworth cycle, the underbidding phase and its benefits for firms cannot be ignored as a valid incentive for firms to follow asymmetric price cycles in dynamic markets without the use of collusive agreements. In the following section I address the concerns about the applicability of both the standard collusion model and Markov Perfect Equilibria to the German Retail gasoline market.

3.3 Application of Theory to the German market

The literature on the pricing patterns in the German retail gasoline market seems ambiguous about the existence of both Edgeworth cycles i.e. Markov Perfect Equilibria (Cabral et Al.) as well as collusive agreements (Linder). While Byrne and DeRoos (2016) can conclude that the pricing patterns found in the Australian market must be collusive due to regulations forcing simultaneous pricing decisions, the same cannot be applied to the German retail gasoline market (Linder, 2018). Gasoline stations in Germany are neither limited in the number of price changes nor the number of price increases per day (Bundeskartellamt). Therefore, one of the key requirements for Markov Perfect Equilibria, sequentiality, cannot be excluded from the German market as in the Australian market. However, while the German retail market may be in principle more favorable towards Edgeworth cycles (Markov Perfect Equilibria), it cannot be described as a duopoly with perfectly homogenous goods. While the behavior of the firms in the market may be in contradiction to the theoretical work on Markov Perfect Equilibria, the focus of the following section lies on if non collusive behavior can be categorically excluded from the retail gasoline market in Germany, as is for instance the case in Australia (Byrne & DeRoos). Therefore, questions about the actual behavior of the firms in the market will be addressed in the empirical part of this thesis, while the theoretical part aims to discuss the extension of the Maskin & Tirole framework to the specific example of the retail gasoline market in Germany.

3.3.1 The number of competitors and product differentiation

Noel (2008) points out that one of the most prominent criticisms of the existence of Edgeworth Cycles[8] in retail gasoline markets regards the number of competitors in the market. While Maskin & Tirole mention the possible existence of Markov Perfect Equilibria in non-duopoly markets, they do not provide an example for such Edgeworth cycles. Noel (2008) extends the models of Maskin & Tirole to fit three competitors and finds that while false and delayed starts may arise, Edgeworth Cycles in the sense of Maskin & Tirole remain possible. Noel (2008) defines false starts as price jumps that are initiated by one firm, but not followed by the other competitors, leading to the initiating firm to return to the competitive level. Delayed starts on the other hand occur when one firm initiates a price jump and remains on that level until the other firms start to raise their prices, starting the undercutting phase (Figure 2).

[8] In the sense of Maskin & Tirole (1988)

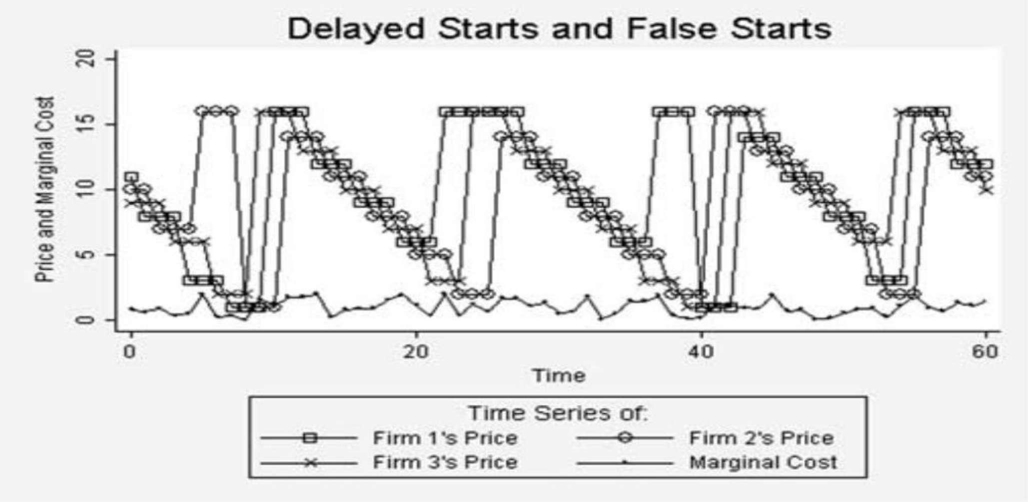

Figure 2 Delayed and False Starts in a triopoly. As is the case in Figure 1, prices are on the vertical and time on the horizontal axis. The first and third price cycles feature a false, the second cycle a delayed start. Source: Noel (2008)

It should be noted at this point that Noel (2008) calculates the feasibility of such triopoly Edgeworth cycles using a simulation that randomizes marginal costs each round among the triopoly firms. Noel (2008) adds these randomized marginal costs due to literary concerns about fluctuating costs in retail gasoline markets around the world, which are not addressed in the model of Maskin & Tirole. Perhaps one of the most interesting implications of Noel (2008) adding marginal costs to the Edgeworth cycle model of Maskin & Tirole is the idea that an increase in marginal costs triggers price jumps, whereas a decrease in marginal costs can prevent other firms from following an already initiated price jump. For instance, in Figure 2, taken from Noel (2008), the first price jump of the graph is initiated by Firm 2, which has to make its pricing decision during a time period with unusually high costs. Firm 3, the next player in line to make a pricing decision, however, does not follow, as marginal costs drop, resulting in a false start.

Table 1: Brand Shares in Hamburg, Germany

Brand	Number of Stations	Market Share in Stations
Aral	46	0.21
Shell	45	0.20
Esso	26	0.12
Jet	20	0.09
Star	17	0.08
Total	12	0.05
Oil!	10	0.05
Hem	7	0.03
Hoyer	6	0.03
Others	32	0.14

Column 1 depicts the brand names, whereas column 2 and 3 depict the number and share of gasoline stations of the respective brands in Hamburg, Germany respectively. The data source of this table is the same as the descriptive part of the analysis i.e. Tankerkoenig.de

The triopoly model of Noel (2008) may be more suitable for the German retail gasoline market. For instance, in Hamburg, over fifty percent of gasoline stations are controlled by three brands (Table 1). However, while the model of Noel may be consistent with regards to the number of competitors, wholesale gasoline prices i.e. the cost of gasoline for retailers in Germany are determined on a daily level (Bundeskartellamt). Price cycles in the German market occur multiple times within a day and thus it does not seem likely that intraday price jumps are triggered by cost increases that change in a daily interval. However, while marginal costs may have less of a role in the intraday price cycles of the German retail gasoline markets, false and delayed starts may arise even in markets with constant costs. Noel (2008) argues that in triopoly markets, following a price increase does not necessarily constitute a best response. Should the first firm initiate a price jump during a price war, underbidding said price jump will not guarantee the entire market demand for the second firm to move, as the third will not have had the chance to raise its prices yet and will remain at the price war level. This means that while in a duopoly, underbidding the initial price jump as a second mover guarantees the entire market demand[9] this no longer applies to the triopoly model, where the second firm i.e. the second mover, no longer offers the cheapest price by underbidding the first firm (Noel, 2008).

[9] The triopoly model of Noel (2008) assumes product homogeneity as is the case in Maskin & Tirole. Noel (2008) puts forward a second extension of the Masink & Tirole model that covers a duopoly with product differentiation.

Therefore, problems with regards to coordination may still arise even without fluctuating marginal costs.

Another concern put forward by Noel (2008) about the application of the Maskin & Tirole model in the gasoline market concerns product differentiation. While the product in the market in and by itself is rather homogenous (Eckert, 2013), spatial considerations such as the distance between gasoline stations need to be considered. Noel (2008) finds that Edgeworth cycles become less stable the higher the product differentiation. This relationship is borne due to the positive relationship between product differentiation and market power. Market power decreases the incentive to undercut the competitor, as the demand gain of a marginal price cut decreases the higher the product differentiation. Noel (2008) finds that after a certain threshold of product differentiation, Edgeworth cycles get replaced by focal prices, another example of a Markov Perfect Equilibrium. Maskin & Tirole (1988) argue that focal prices occur whenever undercutting is less favorable than remaining at a higher focal pricing point. In the case of product differentiation, undercutting becomes less favorable because the increment to gain enough demand needs to be increased, due to customer loyalty. Focal prices differ from Edgeworth cycles in that they do not exhibit cyclical behavior. Instead, firms engaging in a focal price Markov Perfect Equilibrium remain at a relatively high price level.

In summary, Noel (2008) finds that while properties such as product differentiation or triopoly markets may hinder the stability of Edgeworth cycles after certain thresholds, they are not mutually exclusive at lower levels.

3.3.2 The Edgeworth model in a finite setting

Linder (2018) observes that the pricing cycles in Germany occur in a daily interval, with prices surging in the late evening hours and steadily decreasing during the day. Cabral et Al. further observe an additional price jump that interrupts the daily undercutting phase. These observations suggest that the strategic pricing decisions in the German retail gasoline market occur in a daily timeframe. This could lead to the assumption that pricing interactions in the German market are finite, whereas the Edgeworth cycle model of Maskin & Tirole assumes an infinite time horizon, and thus may not be compatible with the German market.

3.3.2.1. Model Buildup

To address the concerns of Edgeworth cycles in a finite game, I suggest an adaptation of the Edgeworth model of Maskin & Tirole constricted by time. Suppose there are two players, Firm

1 and Firm 2 (1). Both players or firms operate in a market over a finite number of periods T with demand (2) and perfect product differentiation, leading to the individual demand function (3). The players compete by setting prices sequentially, with granularity k (4). As is the case in Maskin & Tirole, the production of goods does not incur costs, be they fixed or marginal (5), resulting in profit function (6) in period t (7). The profit function is assumed to be concave, as is the case in the standard Maskin & Tirole model. For simplicity, the time horizon T of this game is limited to allow for less than two full underbidding phases, i.e. the time it takes to reach the competitive price by incremental undercutting from the monopoly price (8).

(1) $Players \equiv Firm_i, i \in 1,2$

(2) Market $Demand \equiv Q(p)$

(3) $Individual\ Demand \equiv \begin{cases} q_i = Q(p), if p_i < p_{j\neq i} \\ q_i = \frac{Q(p)}{2},\ if\ p_i = p_{j\neq i} \\ q_i = 0\ if\ p_i > p_{j\neq i} \end{cases}$

(4) $Granularity \equiv k$

(5) $Individual\ Cost \equiv c_i = 0 = p^C$

(6) Profit in period t $\equiv \pi_i^t(p_i) = p_i q_i,;\ p^M \equiv \max_p[\pi(p)]$

(7) $Period \equiv t \in \{1,2,3,\dots,T\}, where\ T \in (\lambda, 2\lambda)$

(8) $Full\ Underbiding\ phase\ Length \equiv \lambda = \frac{p^M + k - p^C}{k}$

Analogous to the Model of Maskin & Tirole(1988), I define the present and future payoff from playing action[10] a_i as $W_i(a_i, t)$ (9), the payoff one player gets from the other player having played an action $a_{j\neq i}$ is defined as $V_i(a_{j\neq i}, t)$ (10). The value functions (9) and (10) both assume that the players react in accordance with their payoff-maximizing reaction function R_i.

(9) $W_{i,t}(a_i, t) = \pi_i^t(a_i, R_{j\neq i}(a_i, t)) + V(R_{j\neq i}(a_i, t+1))$

(10) $V_{i,t}(a_{j\neq i}, \mathrm{t}) = \max_{a_i} \{\pi_i^t\left(R_i(a_{j\neq i}, t)\right) + W_i(a_i, t+1)\} = \pi_i^t(a_i, R_i(a_{j\neq i}, t)) + W(R_i(a_{j\neq i}, t+1))$

[10] In this case the price.

3.3.2.2. Asymmetric Equilibrium

In the standard, infinite game of Maskin & Tirole, Edgeworth cycle behavior leads to higher profits than pricing at marginal costs, for all parties involved. The major challenge of Edgeworth cycles arises in the coordination of the price jump, as firms prefer to follow a price jump rather than initiating it. Maskin & Tirole circumvent the problem of coordination by arguing that at a certain threshold-price in the undercutting phase, firms will prefer to drop prices to the competitive level and engage in a price war. During the price war phase both firms mix between raising and not raising prices to $p^M + k$ so that they are indifferent between the payoff of the two options, creating a symmetric equilibrium. (Maskin & Tirole pp. A39, 1985)

The profits from following a price jump rather than initiating it is at least as high because in the underbidding phase, the "Follower" gains a head start in the number of periods that incur profits above zero, because it is the first to underbid its opponent, the "Initiator". Given that both firms take turns in underbidding one another, the Initiator can at best only have as many profitable periods as the Follower in the cycle (13). Additionally, in the undercutting phase, underbidding generally leads to lower or equal profits than in the previous periods as the price itself is lower (14). Combining that the Follower has at least many profitable periods as the Initiator, with each of the periods being at least as profitable for the Follower as for the Initiator leads to the conclusion that the profits from following a price jump are at least as high as from initiating ceteris paribus (15). Therefore, as is the case in an infinite model, the question arises under which conditions either of the players would be willing to initiate a price jump, given that following generally leads to higher profits.

(13) $p_i > p_C : \left|\{\pi_i^{2t-1}(p_i): \pi_i^{2t-1}(p_i) > 0\}\right| \geq \left|\{\pi_i^{2t}(p_i): \pi_i^{2t}(p_i) > 0\}\right|, if\ \exists t: p_i^{2t} > p_{j\neq i}^{2t}, \nexists t: p_i^{2t-1} > p_{j\neq i}^{2t-1}$

(14) $\pi_i^t(p_i) > \pi_i^t(p_i - k), if\ p_i < p^M, p_{j\neq i}$

(15) $(13) \wedge (14) \Rightarrow \forall\, \pi_I^{2t} \exists \pi_F^{2t-1}: \pi_F^{2t-1} \geq \pi_I^{2t}, \exists \pi_F^{2t-1}: \pi_F^{2t-1} > \pi_I^{2t} \Rightarrow W(p^M + k) < V(p^M + k)$

While Maskin & Tirole solve the problem of coordination with the help of a discounting factor that punishes players for waiting, I argue that such an instrument is not needed in a finite sequential game. Assume that both players start out by pricing their goods at the cost level, as is the case in the price war phase of Maskin & Tirole, with the goal of making the initiation of a price jump as attractive as possible for the other player. In an infinite setting without discount factors, players would not be able to reach a conclusion as "waiting" for the other player to initiate a jump would not devalue the benefits from the price jump[11]. In a finite setting without discount factors on the other hand, the future payoff of the undercutting phase decreases the further time passes, as the payoff will be cut off at the end of the game (16), where x denotes the periods kept waiting. While one may argue that such a devaluation may enable the existence of a symmetric equilibrium of mixed strategies as is the case in Maskin & Tirole, such an equilibrium may not be resistant to subgame perfection. Consider Table 2, which shows the accumulated profits in the undercutting phase of initiating and following a price jump starting in $t = 0$. Should both players wait for the other player to initiate, the accumulated profits from the undercutting phase will be cut from the lower end of the table, as (16) would suggest. By waiting long enough, there comes a point, where the penultimate player no longer prefers the option of initiating a price jump over continuing the price war, because there will be no time left to underbid the Follower, thus reducing the benefit of the undercutting phase to zero. As the profit of initiating and following a price jump will both lead to payoffs of zero, the player to set the penultimate action in the game will be able to randomize between initiating and following a price jump. By mixing to initiate a price jump below the threshold probability $\underline{\mu}$, the penultimate player can deter the last player from not initiating, as the expected profit from initiating would be higher than not initiating (17). Given that players before the penultimate period prefer to not initiate if they can be sure to follow a price jump in the following period, and that players generally prefer to initiate sooner than later (16), the ultimate player will not be able to convince the other player to initiate a price jump (Figure 2). Backward induction will lead the ultimate player, i.e. the Initiator to the period in the game during which initiation is at least as profitable than in the previous period (18). Therefore, if possible, the Initiator will initiate in the period in which he or she does not forego any profit, i.e. in a period in which the subsequent undercutting phase will not be cut short (19).

(16) $$W_{i,t}(p, t + x) = W_{i,t}(p_i, t) - \sum_{\tau=T-(x-1)}^{T} \pi_i^{\tau} (p_i^{\tau})$$

(17) $$\underline{\mu}\, \pi(p^M) < \pi(p^M - k)$$

[11] The proof of the MPE in Maskin & Tirole (1985, pp A-39) suggests that without a discount factor, the profits from initiating and following a price jump would have to be equal for players to be indifferent. This conclusion is derived by setting the discount factor in (a48) of Maskin & Tirole (1985, pp A-39) to 1.

(18) $\underline{t} \equiv t: W_{i,t}(p_i, t + 2x) \geq W_{i,t}(p_i, t)$

(19) $(16) \land (18) \Rightarrow \underline{t} \equiv t: \sum_{\tau=T-(x-1)}^{T} \pi_i^{\tau}(p_i^{\tau}) = 0$

Table 2: Accumulated Profits in the Undercutting Phase

Period	Accumulated Profit of Initiator	Accumulated Profit of Follower
0	0	0
1	0	$\pi(p^M)$
2	$\pi(p^M - k)$	$\pi(p^M)$
3	$\pi(p^M - k)$	$\pi(p^M) + \pi(p^M - 2k)$
4	$\pi(p^M - k) + \pi(p^M - 3k)$	$\pi(p^M) + \pi(p^M - 2k)$
5	$\pi(p^M - k) + \pi(p^M - 3k)$	$\pi(p^M) + \pi(p^M - 2k) + \pi(p^M - 4k)$
2t	$\pi(p^M - k) + ... + \pi(p^M - (2t - 1)k)$	$\pi(p^M) + ... + \pi(p^M - (2t - 2)k)$
2t+1	$\pi(p^M - k) + ... + \pi(p^M - (2t - 1)k)$	$\pi(p^M) + ... + \pi(p^M - (2t)k)$

The table depicts the accumulated profits of the follower and initiator the undercutting phase. The "Initiator" plays $p^M + k$ in Period $t = 0$, whereas the "Follower" remains at $p = 0$ underbidding the "Initiator in the following period. Note that the calculated profits assume that the price has not reached the lower bound of the undercuttig phase yet.

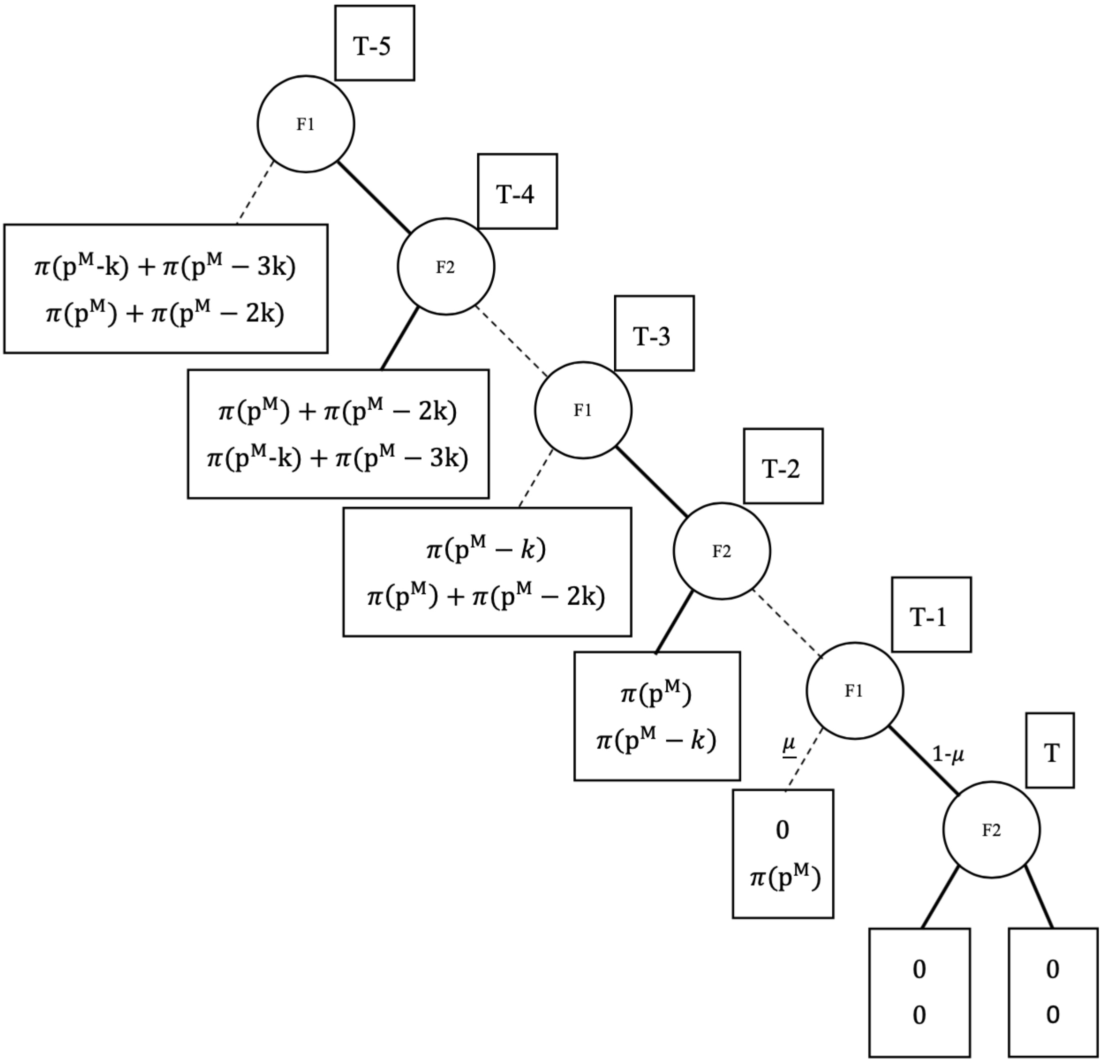

Figure 3: Game tree of the finite sequential model. The square boxes in the top right indicate the period, where T is the ultimate period. The action to the left of the respective information set is the initiation of a price jump. Dashed lines indicate that an action is dominated. Note that $\underline{\mu}$ is chosen such that not initiating dominates initiating a price jump.

The equilibrium in pure strategies found in the finite model differs from the symmetric equilibrium of Maskin & Tirole in that the devaluation incurred by waiting does not directly affect the decision of the players in the current period. Instead, it is the first player to be indifferent between initiating and following, who will be able to credibly put the burden of initiation onto the other player. As such, the Initiator and Follower are determined a priory by the sequence in which they play their actions. It should be noted that this model only considers a span of periods that does not allow for more than one full Edgeworth cycle. By limiting the model to this timeframe, the Initiator will not be able to initiate a price jump earlier to possibly induce the Follower to initiate a price jump.

3.3.2.3. Symmetric Equilibrium in a Semisequential Model

A caveat to this finite sequential model lies in the applicability of the Subgame Perfect Nash Equilibrium. In the German retail gasoline market, each firm is not assigned a specific point in time to change its prices. Therefore, the penultimate period in the game cannot be assigned to one firm, but may, if such a period were to even exist, be chosen by the players themselves. To account for the possibility of players choosing their sequence, I introduce a change to the sequential nature of the game. Suppose now that instead of the players being assigned periods a priori, two players start the game by simultaneously setting prices. The game will remain simultaneous, until the first player sets a price above the cost level. After one of the players set the price above the cost level the other player will be the first player to set an action in a henceforth sequential game. In case both players set a price above the cost level simultaneously, the first player to set the subsequent price will be determined randomly, giving us valuation functions (20)-(22). Apart from the changes in the sequentiality, the remainder of the game is set up as the previous, fully sequential model (1)-(10).

(20) $W_i^t\left(p_i^t = p^M + k, p_{j\neq i}^t = p^C\right) = V^{t+2}\left(p_{j\neq i}^{t+1} = p^M\right)$

(21) $W_i^t\left(p_i^t = p^C, p_{j\neq i}^t = p^M + k\right) = V^{t+1}\left(p_{j\neq i}^t = p^M + k\right)$

(22) $E[W_i^t\left(p_i^t = p^M + k, p_{j\neq i}^t = p^M + k\right)] = \frac{1}{2}V^{t+1}\left(p_{j\neq i}^t = p^M + k\right) + \frac{1}{2}V^{t+2}\left(p_{j\neq i}^{t+1} = p^M\right)$

As is the case in the previous model, I argue that a price jump with a subsequent underbidding phase is possible in a game whose duration does not allow for more than one full undercutting phase. Suppose that both firms start out by pricing at the competitive level. Both firms prefer to engage in a profitable undercutting phase, however, following is preferred over initiating a price jump[12]. By hoping for the other firm to initiate a price jump, the potential gain of the undercutting phase is reduced. The mechanism thereof is the same as in the previous fully sequential model (16), i.e. the undercutting phase is cut off by the end of the game. This loss of future payoff enables us to construct a symmetric equilibrium similar to that of Maskin & Tirole (1985) who utilize a discount factor to punish players waiting for their opposite to initiate a price jump. Should the other player $j \neq i$ decide to randomize between initiating and following a price jump in period t with probability $\mu_{j\neq i}^t$, player i will have to be indifferent

[12] This problem of coordination lies at the heart Edgeworth cycles in Maskin & Tirole (1985)

between initiating a price jump and following (23) for a sequential equilibrium in mixed strategies to exist. Rewriting (23) yields (24), the mixing probability $\mu_{j\neq i}^{t}$ for which player i is indifferent between raising initiating a price jump ad remaining at the cost level. For $\mu_{j\neq i}^{t}$ (24) to be a probability, (25) has to hold. We know from (15) that firms weakly prefer to follow a price jump rather than initiating it, satisfying the first inequality in (25). The second part of the inequality (25) however, is not as easily satisfied and requires further analysis.

$$(23) \quad \mu_{j\neq i}^{t} W_i^t\left(p_i^t = p^C, p_{j\neq i}^t = p^M + k\right) + (1-\mu_{j\neq i}^{t})(W_i^t\left(p_i^t = p_{j\neq i}^t = p^C\right)) = (1-\frac{\mu_{j\neq i}^{t}}{2})(W_i^t\left(p_i^t = p^M + k, p_{j\neq i}^t = p^C\right)) + \frac{\mu_{j\neq i}^{t}}{2} W_i^t\left(p_i^t = p^C, p_{j\neq i}^t = p^M + k\right)$$

$$(24) \quad \mu_{j\neq i}^{t} = \frac{1}{1+\frac{1}{2}\frac{W_i^t\left(p_i^t=p^C, p_{j\neq i}^t=p^M+k\right)-W_i^t\left(p_i^t=p^M+k, p_{j\neq i}^t=p^C\right)}{W_i^t\left(p_i^t=p^M+k, p_{j\neq i}^t=p^C\right)-W_i^t\left(p_i^t=p_{j\neq i}^t=p^C\right)}}$$

$$(25) \quad W_i^t\left(p_i^t = p^C, p_{j\neq i}^t = p^M + k\right) \geq W_i^t\left(p_i^t = p^M + k, p_{j\neq i}^t = p^C\right) > W_i^t\left(p_i^t = p_{j\neq i}^t = p^C\right) \Longrightarrow \mu_{j\neq i}^{t} \in [0,1]$$

Table 3: Accumulated Profits in the Final Periods of the Game

Period t	$\mathrm{W}_i^t\left(p_i^t = p^M + k, p_j^t = p^C\right)$	$\mathrm{W}_i^t\left(p_i^t = p^C, p_j^t = p^M + k\right)$	μ_j^t
T	0	0	0
T-1	0	$\pi(p^M)$	0
T-2	$\pi(p^M - k)$	$\pi(p^M)$	μ_j^{T-2}
T-3	$\pi(p^M - k)$	$\pi(p^M) + \pi(p^M - 2k)$	0
T-4	$\pi(p^M - k) + \pi(p^M - 3k)$	$\pi(p^M) + \pi(p^M - 2k)$	μ_j^{T-4}
T-5	$\pi(p^M - k) + \pi(p^M - 3k)$	$\pi(p^M) + \pi(p^M - 2k) + \pi(p^M - 4k)$	0

The table depicts the accumulated profits of the follower and initiator the undercutting phase as well as the mixing probabilities μ_j^t in the last periods of the game. If μ_j^t is not set to zero it means that the mixing probabilities cannot be excluded. Should μ_j^t be zero, a mixing equilibrium can be excluded.

Consider the penultimate period in the game, T-1 (Table 3). While following leads to a higher profit than initiating, the payoff of neither player initiating is equal to the payoff of just one player raising the price. Therefore, (25) cannot hold and (24) would not be defined. In the previous period T-2 on the other hand, the absence of a mixed equilibrium in T-1 means that the payoff of neither player initiating [13] remains at zero. The profit of initiating in period T-2 however, lies above zero as can be seen in Table 3, meaning that there exists a mixing probability in T-2.

The previous period, T-3 cannot exhibit an equilibrium in mixed strategies due to the following properties: The payoff from neither player initiating a price jump is determined by the expected profits from the later periods (26). Said expected profit on the other hand can be set to zero if no equilibrium in mixed strategies can occur in the period[14]. Therefore, the only periods that are relevant for the payoff in (26) are those in which an equilibrium in mixed strategies exists. We know from (23) that the players must be indifferent in periods in which a mixed strategy equilibrium exists, therefore, we can rewrite (26) as (27).

Because there exists an equilibrium in mixed strategies in T-2, for (25) to hold, the payoff of initiation in T-3 must be larger than the expected profit of the mixed strategies in T-2 (27), which cannot hold as the lowest possible outcome in (27) delivers the same payoff as initiation in T-3. This result can be generalized for periods that immediately predate a period that allows for a mixed strategy equilibrium. If the period $T-2x$ exhibits the same profit for initiation as in $T-2x+1$, the mixed strategy in $T-2x+1$ will lead to an expected profit that must be at least as big as that of initiation in $T-2x$, as the profit of following in $T-2x$ is higher than the profit of initiating in $T-2x+1$. This means that at best, only periods $T-2x$ can exhibit mixed equilibria.

Therefore, given that price jumps in pure strategies would not be feasible as following is preferred over initiating[15], for a mixed strategy in price jumps to exist, the expected payoff from initiating must be larger than the expected payoff of the first next period in which a price jump is possible (28).

(26) $$\text{if } \exists \mu^{t+x} \in (0,1) \implies E[W^{t+x}(\mu^{t+x})]) = (1-\frac{\mu_{j\neq i}^{t+x}}{2})(W_i^{t+x}\left(p_i^{t+x}=p^M+k, p_{j\neq i}^{t+x}=p^C\right)) + \frac{\mu_{j\neq i}^{t+x}}{2} W_i^{t+x}\left(p_i^{t+x}=p^C, p_{j\neq i}^{t+x}=p^M+k\right)$$

[13] i.e. $W_i^t\left(p_i^t = p_{j\neq i}^t = p^C\right)$

[14] Periods that do not allow for mixed strategies lead to profits of zero as a price jump is unstable in pure strategies.

[15] Except for the last period T, as jumps in that period do not deliver any benefit

(27) $(15)\wedge(W_i^t(p_i^t = p^M + k, p_{j\neq i}^t = p^C) = (W_i^{t+1}(p_i^{t+1} = p^M + k, p_{j\neq i}^{t+1} = p^C)\wedge(\mu^{t+1} \in (0,1)) \Rightarrow E[W_i^{t+1}(\mu^{t+1})] > (W_i^{t+1}(p_i^{t+1} = p^M + k, p_{j\neq i}^{t+1} = p^C)$

(28) $W_i^t(p_i^t = p^M + k, p_{j\neq i}^t = p^C) > (E[W^{t+x}(\mu^{t+x})])\wedge 0 \Longrightarrow \mu_{j\neq i}^t \in [0,1], where\ t + x = min(t + x \in T: \exists\mu^{t+x})$

(29) $\nexists\mu^t \in (0,1): t \neq T - 2 \Longrightarrow E[W^{T-2}(\mu^{T-2})] > (W_i^t(p_i^t = p^M + k, p_{j\neq i}^t = p^C)\forall t < T - 2$

While condition (28) does not hold true for every period, it must hold true in T-2. Furthermore, the farther away the next period in which a mixed strategy equilibrium exists, the more likely it is for condition (28) to hold, as generally speaking profits for both following and initiating are lower in later periods. Consequently, for there to be no mixing probability in any period apart from T-2, the payoff of initiation in any given period must never exceed the expected payoff of T-2 (29).

Therefore, I cannot exclude the possibility of non-collusive equilibria in a finite market, even if the order of players is not fixed yet. It should be mentioned, that this semisequential as well as the sequential model in finite periods thus far has only been applied in markets where two firms compete in a period that allows for no more than one full underbidding phase. Results may differ if the model is extended to fit for multiple price cycles, for instance firms may be willing to initiate one price jump prematurely in the hopes compelling the other player to initiate price jumps in later periods. However, conclusions about such extensions at this stage are purely speculative and require further analysis.

3.4 Implications for the Empirical Analysis

In this section two general groups of equilibria are examined: collusive and non-collusive equilibria. For the sake of clarity, collusive equilibria in this thesis are defined as those who are sustained by multi game agreements, i.e. the folk theorem and would not be stable by themselves. Non collusive equilibria such as Edgeworth cycles in the sense of Maskin & Tirole, i.e. Markov Perfect Equilibria, or extensions thereof on the other hand do not require such agreements as they are stable equilibria in themselves. Given that we cannot exclude either equilibrium definition by the shape of the cycles alone (Linder, 2018), we have to resort to another empirical strategy.

Maskin & Tirole argue that Edgeworth cycles that are formed by Markov Perfect Equilibria do not require players to consider any action in the past that is not directly payoff relevant. The breach of a collusive agreement and the subsequent punishment by the competitors is therefore mutually exclusive with Edgeworth cycles in the sense of Maskin & Tirole. Therefore, the first part of the empirical analysis will focus on changes in the pricing patterns in the market and determine if the changes can be seen as breaches in collusive behavior and subsequent punishment.

However, as is hinted by Cabral et Al. (2018), the intraday pricing cycles in the German gasoline market need not be of the same equilibrium concept. As such, it is not impossible that some pricing cycles remain immune to the change in pattern of one of the intraday cycles. T show the incompatibility of all intraday pricing cycles in the market with non-collusive equilibria, the second part of the empirical analysis focuses on the repetitiveness and consistency of the price cycles. Apart from the fully sequential model in finite periods from section 3.3.2.2. which exhibits a Subgame Perfect Nash equilibrium, Maskin &Tirole (1988), Noel (2008) as well as the semi sequential model from section 3.3.2.3. hint towards price jumps being initiated in a random manner. This is due to the idea that price jumps are preferably followed, instead of initiated. Penalties for both players waiting, such as discount factors in Maskin & Tirole (1985) or the approaching end of the game in the finite model, allow for such mixed strategies to occur in the first place.

The patterns in the German gasoline market thus far have been reported to exhibit asymmetric pricing cycles, i.e. sharp price jumps with incremental underbidding phases (Linder), (Cabral et Al.). The literature thus far disagrees on whether such pricing patterns are part of a Markov Perfect Equilibrium, or collusive. In the following section I analyze the pricing patterns of the largest three retail gasoline brands in Hamburg Germany from 2014 to 2022. Changes in the predominant pricing patterns as well as their repetitiveness are of interest in the analysis. Should price jumps indeed be repetitive and occur in certain focal points, this may towards price jumps coordinated at focal points and not in mixed equilibria. It should at this point be considered that the theoretical part of this thesis cannot cover all possible forms of non-collusive equilibria that could arise in a sequential market. However, one of the most important mechanisms behind non collusive equilibria such as Markov Perfect Equilibria or derivations thereof in the context of price cycles seems to be the mixed strategy equilibrium.(Maskin & Tirole, 1985) According to Maskin & Tirole, as well as the derivation thereof in a finite game, as long as initiating price cycles remains a public good, reliably initiating price cycles in pure strategies cannot be a stable (non-collusive) equilibrium option.

4. Descriptive Analysis

In the descriptive part of this thesis, I examine the pricing patterns of the retail gasoline market in Hamburg Germany, from 2014 to 2020. The approach chosen is descriptive, as is the case in other literature on pricing patterns in retail gasoline markets, most notably Byrne & DeRoos. Asymmetric pricing cycles alone are not a definitive proof for Edgeworth cycles sustained by a Markov Perfect Equilibrium according to Linder (2018). For instance, Byrne & DeRoos show asymmetric pricing cycles resembling Edgeworth cycles in a market that imposes simultaneous pricing, which excludes Markov Equilibria. Therefore, to gain insight into the equilibrium concepts behind the patterns in the German market, a different approach may be required. As argued in the previous section, Edgeworth cycles as Markov Perfect Equilibria exist primarily in mixed strategies, both in finite and infinite games (Maskin & Tirole, 1988). Mixed strategies are required for such Markov Perfect Equilibria as initiating price jumps generally leads to lower payoffs than following price jumps (Maskin & Tirole, 1985).

Coordinated price jumps in focal points may deliver an alternative explanation to mixed strategies. Such strategies have been documented in other retail gasoline markets such as Australia (Byrne & DeRoos) however, they cannot constitute a Markov Perfect Equilibrium, as they require information from previous periods to become an equilibrium. Maskin & Tirole define a Markov Perfect Equilibrium to not require players to make agreements or even consider past actions that are not directly payoff relevant. Therefore, focal points established in previous days would be a violation thereof. Furthermore, an agreement in pure strategies to initiate a price jump is not feasible if there is an incentive to deviate from said agreement. It would require supergame agreements, that disincentivize deviation from the agreement (Tadelis, 2013).

I bifurcate the descriptive analysis into two sections. In the first section I analyze the general evolution of the pricing patterns with a focus on the period between 2017 and 2019. As can be seen in Figure 4, the daily number of price jumps by brand increases during this period and may deliver insight into the equilibrium concept behind the price cycles. Specifically I am interested in breaks in existing patterns, to identify deviations of possibly collusive agreements. In the second section I analyze the repetitiveness of the patterns to gain insights into whether price jumps are initiated at focal points in pure strategies or if they are randomly initiated.

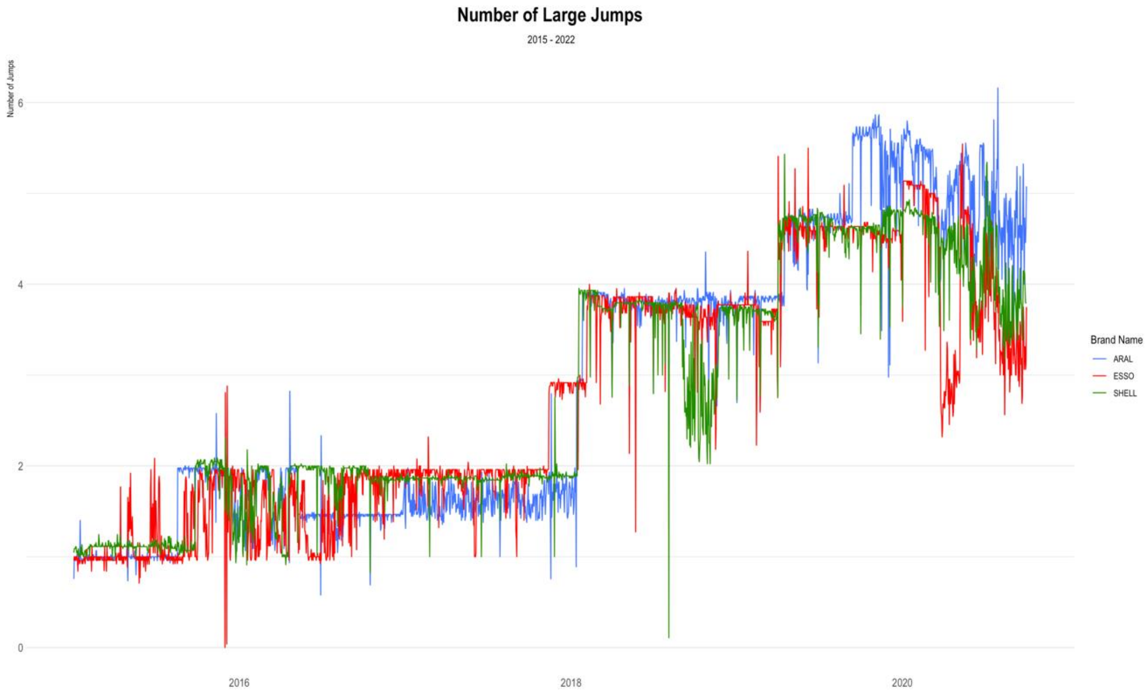

Figure 4: Average number of price jumps above 5 Cent (Euro) from 2014 to 2022. Each observation is the average number of price jumps by brand on a given day. Note the sharp increase in the number of price jumps at the start of 2018 in the middle of the graph.

4.1 Data

4.1.1. Data Source

Gasoline stations in the German market are required by law to upload fuel-price changes to the German competition authority (German Ministry of Justice), which can then be accessed by transparency services, such as the German automobile club (ADAC) or Tankerkoenig.de. The primary purpose of such price transparency websites is for potential customers to compare the prices between gas stations in the area by accessing these transparency websites that offer real time price information on gasoline stations in their area. Such websites are not unique to Germany, other retail gasoline markets such as in Austria or Australia[16] have similar programs in place. Tankerkoenig.de offers historic pricing data on the universe of the German retail gasoline market under a creative commons license in addition to its price transparency services for customers. The pricing dataset includes the minute of the price change as well as the station id, whereas station level data includes geographic variables such as the city, zip code,

[16] Byrne & DeRoos use data from Australian price transparency websites

coordinates as well as the brand name. I restrict my analysis to E5 gasoline pricing patterns in the city of Hamburg between 2015 and 2020. Other variants of fuel in the dataset include Diesel and E10, the difference between E10 and E5 being the percentage of Ethanol in the fuel. Furthermore, for the purpose of visibility I focus only on the three largest brands in the market by brand share, namely Aral, Shell and Esso[17]. The underlying assumption on using the brand level price average as the main unit of observation requires the pricing decisions of the gasoline stations to be made by their respective brand is supported by existing literature on the German retail gasoline market such as (Linder, 2018). I therefore deduce that the pricing decision of each brand can be approximated by the average price conditional on brand. Such approaches are not a novelty in the literature but have been implemented by other authors already, most notably Byrne & DeRoos.

One of the main units of observation in the analysis of the pricing patterns in the retail gasoline market is the pricing average conditional on time and brand. As the pricing data provided by tankerkoenig.de only provides price changes and not the price of a gasoline station at a given point in time, to calculate the average price by brand in each point in time I create a dataset that includes the price of every station at any given minute. However, given the computational effort on creating such datasets, their scope is limited to no more than a few weeks. To identify changes in the pricing patterns over a rather considerable period (2015-2020) I utilize two approaches: interval halving search as well as daily data on the number of price changes.

I supplement the pricing data with data on the cost of gasoline in the wholesale market. This data is obtained directly from Boeschenergy GmbH, a company in the Austrian retail gasoline market. The delivery agreement between Boeschenergy GmbH and its primary supplier builds on what is referred to as monthly terms of gasoline prices. The cost of gasoline and similar products such as diesel is determined at the end of each month, by the average of the daily closing prices on oil future indices. The average is weighted equally by each day, meaning that the volume sold does not affect the monthly term. Refinery costs as well as taxes apart from the VAT are added to these terms, while transportation costs are not included. Given the agreement with the wholesale supplier, the cost of gasoline on each day is not the daily value of the closing prices but the average of the daily prices so for each month (1). Differences between the costs in the German retail gasoline market thus arise in taxes, logistics and the calculation of the terms (2). While taxes can be accounted for, unobserved differences such as

[17] See Table 2 in section 3.3.1. A similar selection has been employed by Linder (2018)

wholesale transportation costs and wholesale agreements may introduce divergence (3). Therefore, the difference between costs and prices should not be used as a precise indicator for the competitiveness. However, changes in the costs may be helpful in determining shocks on the gasoline market if it is assumed that the variance in the wholesale gasoline prices is driven by factors outside of Austria, such as crude oil prices and refinery costs, which may experience at least some similarity between the Austrian and German market. (Boeschenergy GmbH)

(1) $$Cost_{t,Boeschenergy\ GmbH} = \frac{\sum_1^t Daily\ Term(Stock\ Index\ Price,\ \ Austrian\ Refinery\ surcharges)}{t}$$

(2) $$Cost_{t,German\ Gasoline} \approx Cost_{t,Boeschenergy\ GmbH} + German\ Taxes\ on\ Gasoline + German\ VAT - Austrian\ Taxes\ on\ Gasoline + \Delta Unobserved\ Factors$$

(3) $$\Delta Unobserved\ Factors \approx German\ Logistic\ Costs - Austrian\ Logistic\ Costs + \Delta\ Wholesale\ Agreements$$

4.2. Pattern Evolution

From 2014 to 2020, the pricing interactions between brands undergo several changes, most notably the shape of the pricing cycles and the frequency thereof. For the purpose of this thesis I distinguish between two shapes of price cycles that occur in the retail gasoline market in Hamburg, Germany.

Nighttime Price Jumps (NPJs)*: Price jumps that are initiated around the nighttime hours. These jumps are followed by a few hours of price stability at a high level, with the subsequent underbidding phase initiated in the morning hours*

Daytime Price Jumps (DPJs): *Price jumps that are not initiated around the nighttime hours. Opposed to Nighttime Price Jumps (NPJs) Daytime Price Jumps (DPJs) prices decrease directly after the initial jump.*

From 2014 to 2015, price jumps can almost exclusively be categorized as NPJs, as can be seen in Figure 5. Whereas the NPJs are characterized as Edgeworth cycles by Cabral (2018), there are some features which seem inconsistent with Edgeworth cycles sustained by a Markov Perfect Equilibrium. Regardless as to how a price jump is initiated, it is in the best interest of the other firm to marginally underbid the initiator. This does not seem to be the case in Figure 5, less so in later periods compared to DPJs (Figure 6). Furthermore, the timing of the price jump raises further questions. Assuming that pricing decisions may not be followed as quickly during the nighttime due to personnel reasons[18] the question arises why firms would initiate price jumps at night when they are less likely to check if their competitors underbid them due to standard office hours.

Figure 5 Nighttime Price Jumps from March 2nd to March 8th 2015. Price levels peak around midnight every day. Price levels are at the brand level average. Note the asymmetry in size between price increases and decreases. Said asymmetry decreases for Nighttime Price Jumps over time.

[18] Algorithmic pricing software was introduced in the German retail gasoline market only during 2017 according to Assad et Al. (2020)

Figure 6: Average price levels by brand in late June and early July 2015. As in Figure 5, the large price jumps are centered around midnight and thus are a convenient tool for orientation. The undercutting phase between price jumps is interrupted by the first occurrence of DPJs by late June as can be seen after the fourth price jump from the left.

The underbidding phase of the NPJs that occur in a daily interval is interrupted by DPJs by June 2015 (Figure 6). On June 24th [19] Aral starts to repeatedly increase its prices around 12 pm, however it takes only one day for the other firms to follow. Cabral et Al. (2018) argue that the DPJs are caused by the introduction of a price matching guarantee by Shell earlier in 2015 (Figure 7). This price matching guarantee allows members of the Shell Clubsmart Program to buy gasoline at the lowest rate in the market (Cabral et Al.).The mechanism behind the price matching guarantee put forward by Cabral is designed as a classic prisoner's dilemma as is used in the literature on collusive agreements. (Cabral et Al.) Cabral et Al. argue that the price matching guarantee cushions the loss of customers if one of the firms decides to deviate from the collusive agreement, in this case the price jump, and thus makes the collusive agreement more attractive to firms. However, one caveat in the explanation of Cabral et Al. lies in the root cause of the dilemma behind the initiation of price jumps in sequential games. Maskin & Tirole (1985) argue that price jumps are public goods that are marginally underbid as a best response by the other player when initiated. Therefore, in a sequential game, players that initiate a price

[19] The fourth of the large price jumps in Figure 6 marks the start of June 24th 2015

jump expect to be underbid. Instead, the question arises as to which player relents first and raises the price. Given that the underbidding phase is less profitable for the initiating firm, the price matching guarantee could reap some of the profits of the following firm, and thus make initiation more attractive, however this does not give a definitive answer on the equilibrium concept behind the midday price jumps.

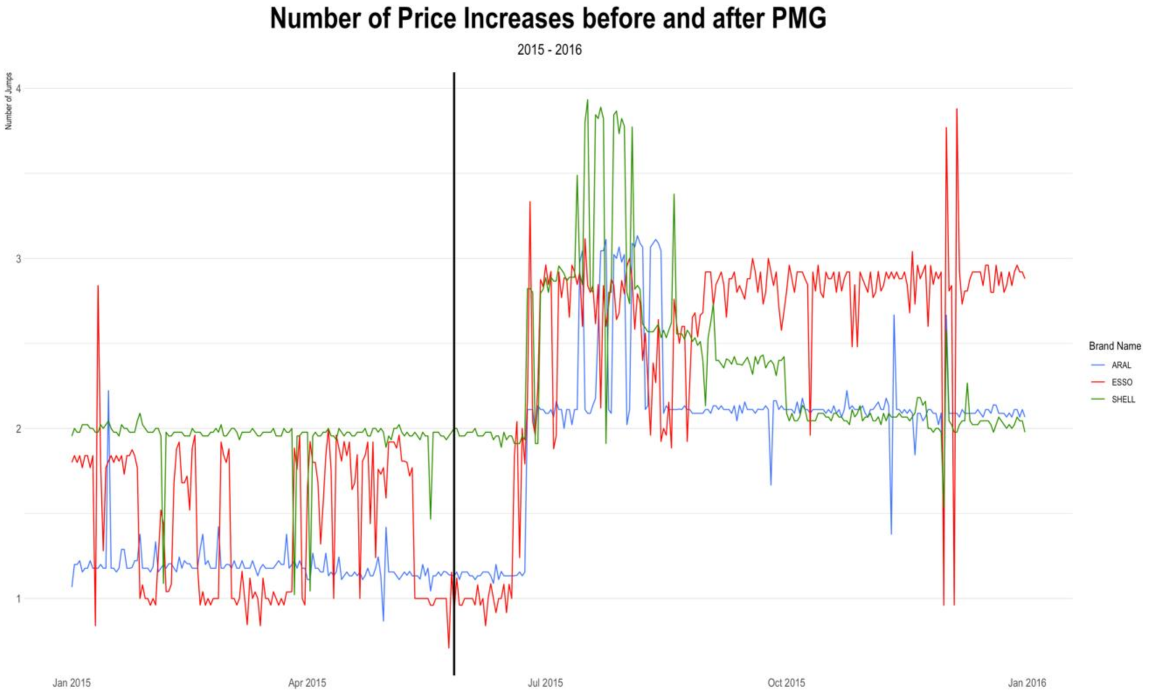

Figure 7: The average daily number of price increases by brand before and after the introduction of the Price matching guarantee. the vertical line represents the introduction of the PMG by Shell as argued by Cabral et Al. (2018).

NPJs as well as DPJs are prevalent in the retail gasoline market in Hamburg from 2015 to 2018. Most notably, the frequency of DPJs increases in that period, leading to a recurring pattern with one NPJ and two DPJs per day (Figure 8). The difference between DPJs and NPJs can be seen in Figure 8. The undercutting phase promptly follows in DPJs, therefore seeming much more consistent with asymmetric price cycles suggested by the literature. The NPJs in late 2017 to 2018 do not resemble Edgeworth cycles, given their relative absence of asymmetry. The breakdown of the NPJs in early 2018 and subsequent efforts by other firms to reinstall NPJs give more insight into the equilibrium concept behind the NPJs.

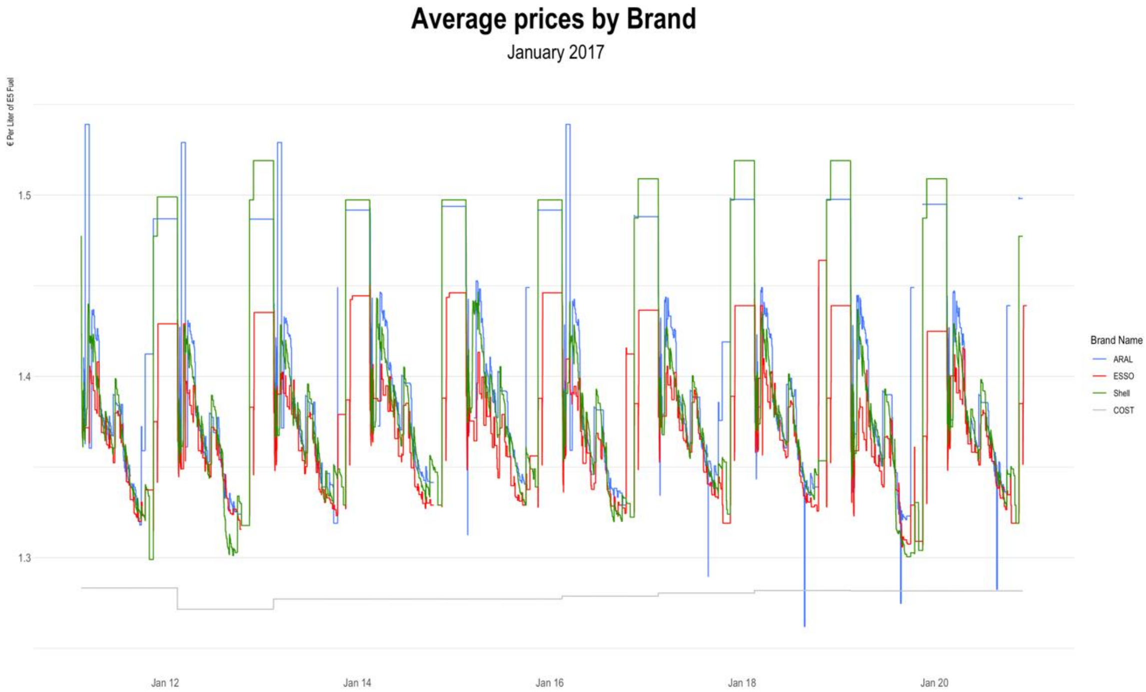

Figure 8 Average price levels by brand in Hamburg, Germany from January 11th to January 21st 2017. Note the difference between asymmetric (triangular) DPJs and symmetric(rectangular) NPJs. As is the case in the previous figures, NPJs occur once a day around midnight and are initiated at 10 pm. While price levels remain relatively high after the initial jump in NPJs, the undercutting phase is initiated immediately in DPJs.

On January 12th, Shell and Aral do not raise their prices during the night. However, contrary to Shell, Aral repeats its behavior[20] on the following weekend i.e. January 13th and January 14th, prompting Shell to lower its prices during the night (Figure 9). Subsequently Shell does no longer initiate NPJs for the remainder of the observational period, prompting both and Aral and Esso to lower their nighttime price levels. The resulting pattern as can be seen in *Figure 10* shows relatively low prices during the night. Pricing patterns from 2018 to 2020 no longer exhibit the NPJs that are characteristic of the gasoline market up until that period. Efforts of Aral to reinstate NPJs in late March of 2019 (*Figure 11*) do not convince Shell to follow suit. Contrary to its best response, Shell does not even raise its price during the night to marginally underbid its opponent but remains at a low level throughout the nighttime. This deviation from a best response leads to the conclusion that Shell is indeed punishing its competitors for the breakdown of the NPJs in 2018. Such behavior, however, is inconsistent with the theory of Edgeworth cycles according to Maskin & Tirole (1988), and hints more towards the breakdown

[20] i.e. not raising prices during the night.

of a collusive agreement stabilized by a trigger strategy. Markov Perfect Equilibria are characterized by the absence of supergame agreements such as trigger strategies. Instead, players utilize only information that is directly payoff relevant from the past i.e. the current prices of the competitors to maximize their future payoffs. This excludes actions such as deviations from previous days.

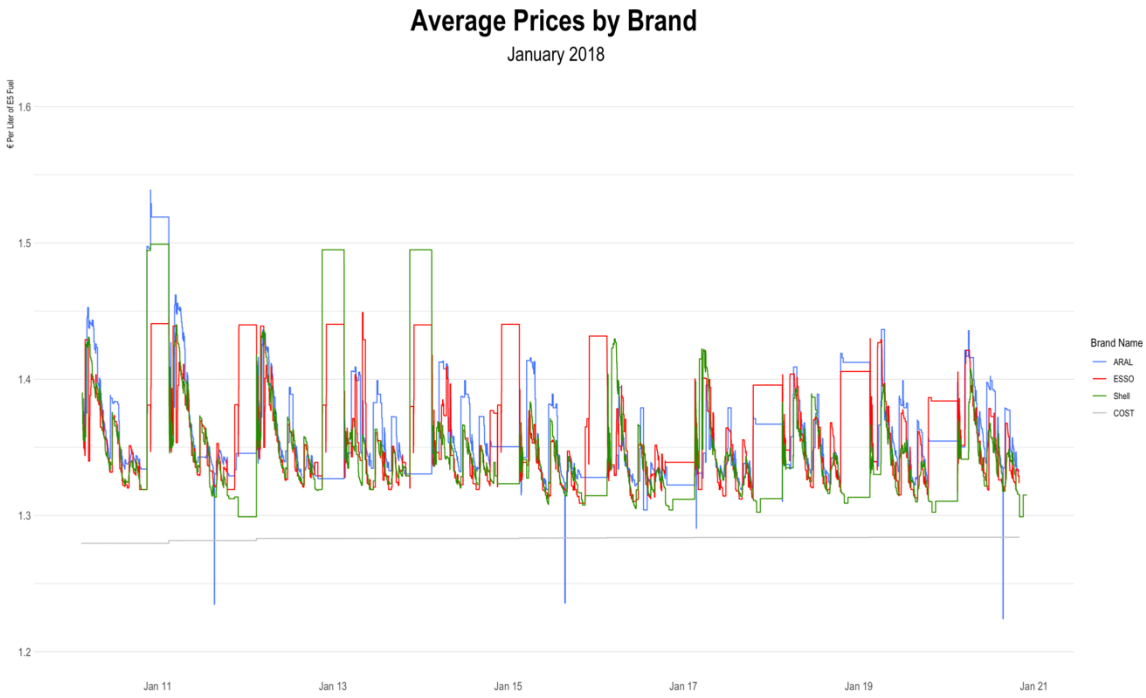

Figure 9: Average price levels by brand in Hamburg, Germany from January 10th to January 21st 2018. Note the deviation by both Shell and Aral from NPJs in the night from January 11th to January 12th. While Shell reintroduces the NPJs in the night from January 12th to January 13th, Aral remains at a low-price level on this weekend. Thereafter, Shell no longer follows the NPJ pattern, despite efforts by Aral to reintroduce NPJs, e.g. on the night from January 17th to January 18th.

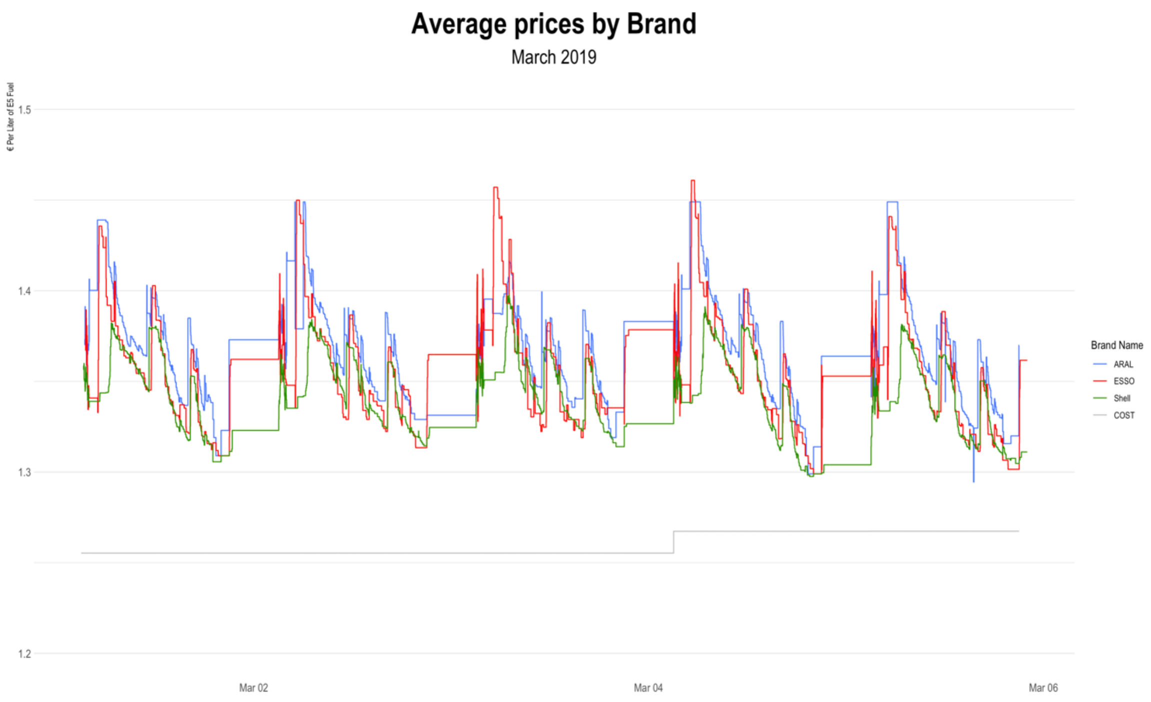

Figure 10: Average price levels by brand in Hamburg, Germany from March 1st to March 6th 2019. Note that while Esso and Aral raise prices by a bit during the night (10 pm), Shell does not. Furthermore, the price level of Aral and Esso during the night is below the peaks of the DPJs.

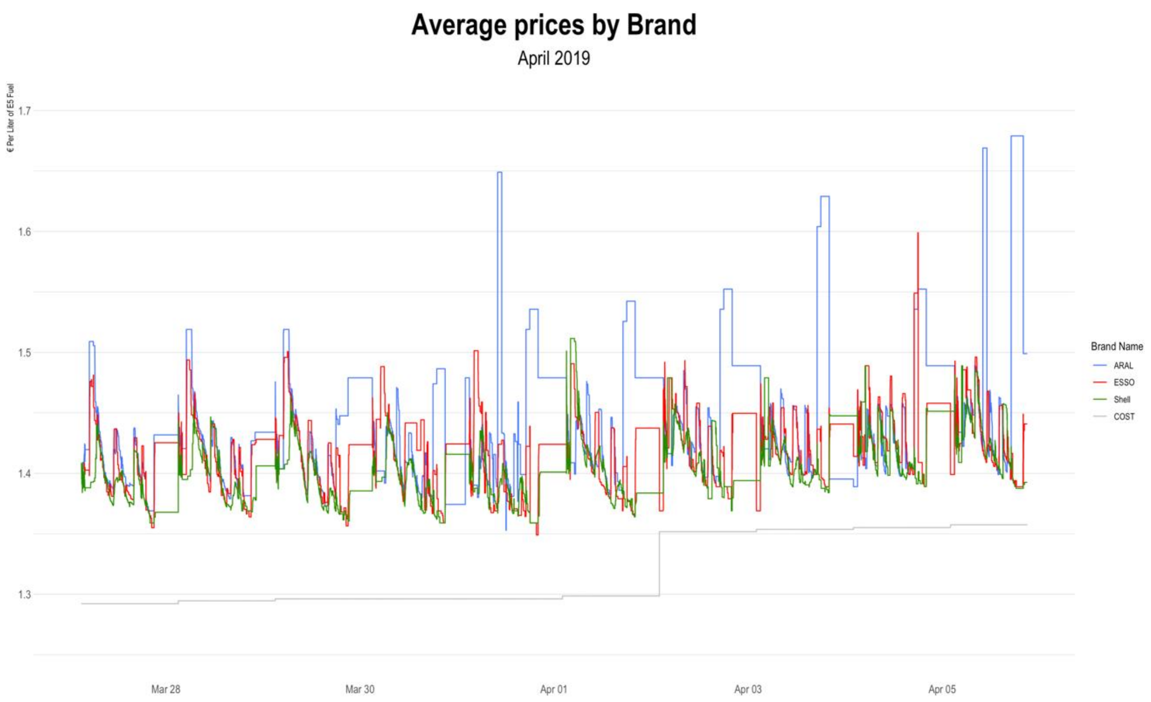

Figure 11: Average price levels by brand in Hamburg, Germany from March 27th to April 6th 2019. Note the efforts by Aral to reintroduce NPJs on the night from March to April and onwards. Price levels of Shell remain at a low level, independent of the actions that Aral takes.

While NPJs no longer occur after 2018, DPJs remain in the pricing interactions between brands until the end of the observational period. Furthermore, after the start of 2018, the number of DPJs increases from three (Figure 10) to at least five (Figure 12). One of the explanations for this increase in DPJ frequency per day may be the decrease in reaction time between firms, which can be approximated by the number or price cuts per day (Figure 13). By decreasing the reaction time, i.e. increasing the possible interactions between firms in a given 24 hour interval, more undercutting phases would fit into a 24 hour timeframe and thus more pricing cycles[21]. However, even though this decrease in reaction time would explain as to why it is possible to fit more pricing cycles into a given interval, it does not answer the question as to how the initiation of such DPJs is coordinated. In the following section I analyze the timing of the DPJs, to determine whether such price jumps are indeed sustained by mixed strategies, or if there are focal points in the market with which the firms coordinate price jumps and thus inconsistent with the idea of a Markov Perfect Equilibrium.

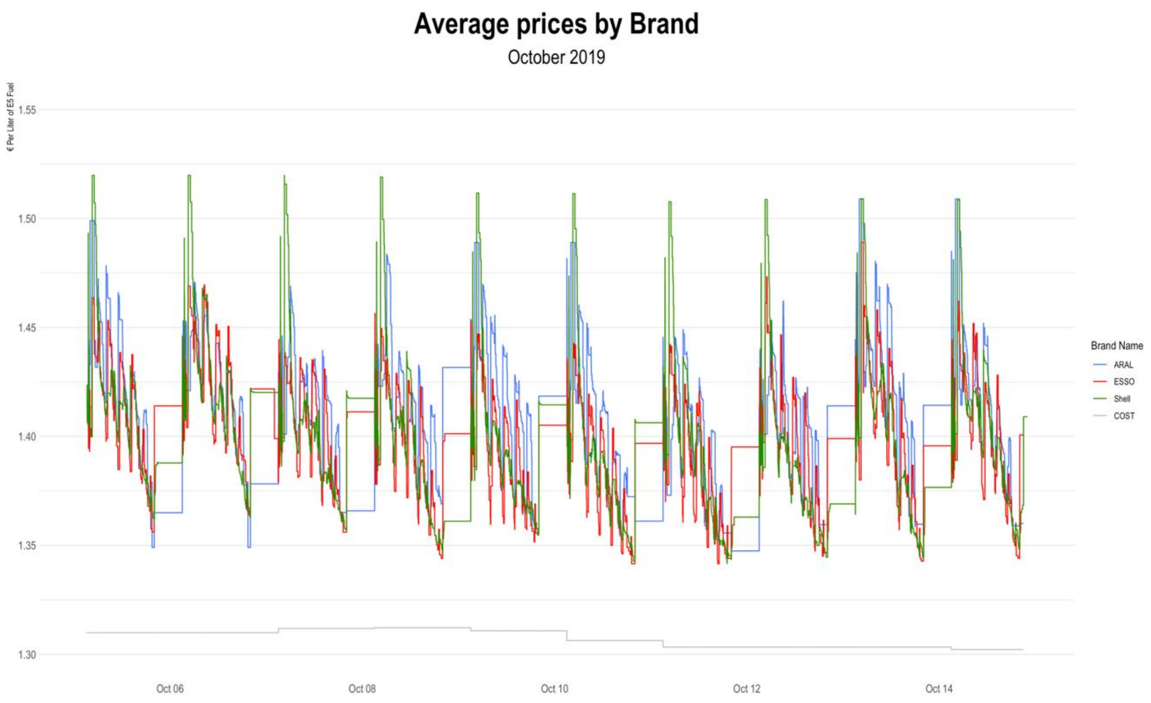

Figure 12 : Average price levels by brand in Hamburg, Germany from October 5th to October 15th 2019. Note the increase in frequency of DPJs per day compared to Figure 10.

---

[21] Ceteris paribus

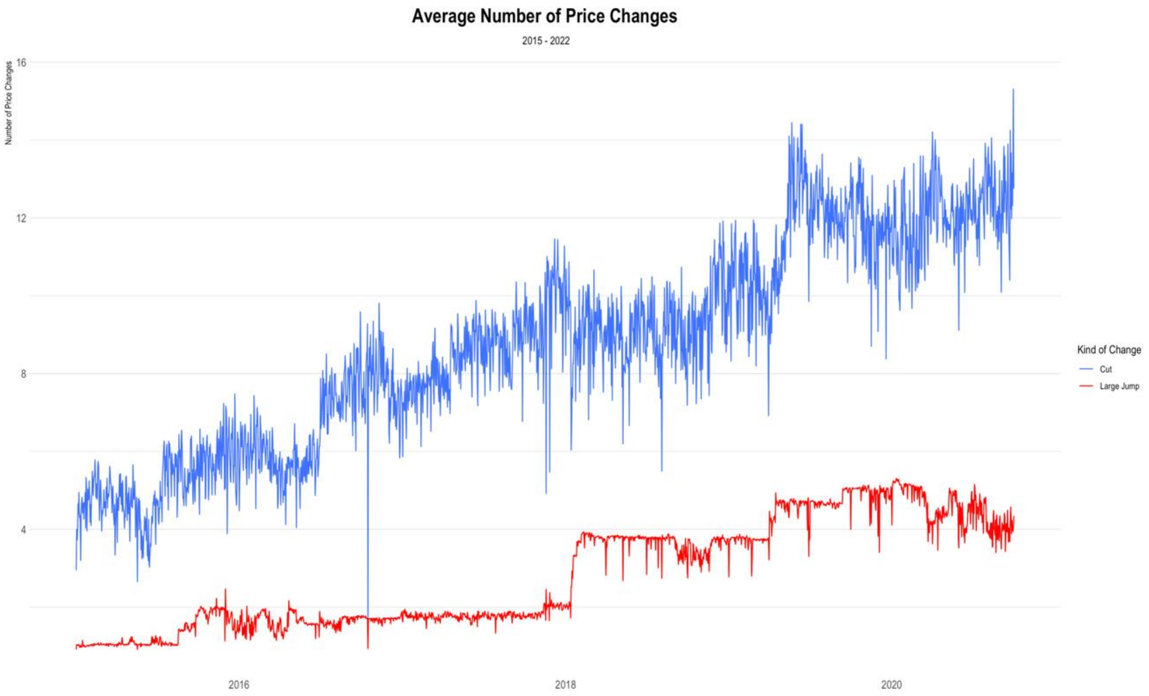

Figure 13: The average number of price jumps (red) and price cuts, i.e. decreases (blue) in Hamburg, Germany from 2015-2020. Observations are on the daily level. While both kinds of price changes increase over time, the number of price jumps seems to increase less fluidly than that of price cuts. One explanation for this could be that price jumps require more coordinating effort than price cuts.

4.2. Consistency of the price jumps

While the idea of NPJs being sustained by a Markov Perfect Equilibrium seems rather implausible, the question remains how to categorize the equilibrium behind the DPJs. The Shape of DPJs as can be seen in Figure 10 is reminiscent of Edgeworth cycles, however as is stated by Linder (2018), asymmetry alone does not guarantee that pricing cycles are Edgeworth cycles in the sense of Maskin & Tirole. For instance, price jumps could be initiated with the help of a collusive equilibrium, with players engaging in an undercutting phase after the collusive price jump. The shape in and by itself would therefore not differ from that of a non-collusive in which jumps are initiated with mixed strategies. One of the key challenges for Edgeworth cycles lies in the public goods dilemma of initiation (Maskin & Tirole). Firms strictly prefer to not initiate a price jump if they can be sure that their opposite will initiate in the next round. Therefore, a symmetric Edgeworth equilibrium in the sense of Maskin & Tirole can only occur in mixed strategies[22].

Byrne & DeRoos (2016) show that firms in the Australian retail gasoline market use focal points to coordinate price jumps. Such strategies cannot be excluded from the German retail gasoline market a priori, however, they are in direct violation with the definition of a Markov Perfect Equilibrium which is defined as follows:

*"**A Markov perfect equilibrium** is a perfect equilibrium. That is, given that its rival ignores all but the payoff-relevant history, a firm can just as well do the same.", Maskin & Tirole (1988)*

Therefore, if firms were to utilize specific points in time, e.g. 12pm, to coordinate price jumps, such equilibria could not be Markov Perfect Equilibria by definition. Furthermore, an agreement in pure strategies between firms to raise prices at a specific point in time would not be consistent with the non-collusive agreements in Edgeworth cycles of Maskin & Tirole (1988) due to the public good dilemma. One exception thereof would be the first model of this thesis, i.e. the extension of the Edgeworth Model of Maskin & Tirole, in which the sequence of players is fixed. However, the stabilizing mechanism of this model, the sequence of the players determining the initiator of the price jump, does not seem to be representative of the German retail gasoline market. As such, it seems that non-collusive mixed strategy equilibria circumventing the public goods dilemma of initiating price jumps are the only viable alternative to collusive equilibria as an explanation for the pricing patterns in the German retail gasoline market.

The Daytime price jumps in the German retail gasoline market show a high degree of consistency across days. In March 2019, DPJs are initiated on four specific times a day: 07:00 am, 12:00pm, 17:00pm, as well as 22:00, as can be seen in Figure 14. These four focal points, however, are not only present in 2019 but date back to a least 2018, around the time when Aral deviated from raising the prices in the nighttime (Figure 15). Indeed the last focal point of the day at 10 pm in Figure 14 is a remnant of the DPJs before 2018, which were initiated at 10 pm each day (Figure 15).

[22] The SPNE in the finite period Edgeworth Model would be an exception. However, as discussed earlier, the mechanism behind this pure strategy equilibrium cannot be applied to the German retail gasoline market as the penultimate period to set prices is not assigned to a firm a priori.

This consistency in the timing of the price jumps not only between days but across years makes the idea of DPJs initiated by non-collusive equilibria in mixed strategies implausible. Much rather it seems that price jumps in the German retail gasoline market are price jumps in pure strategies that are initiated at focal points. Focal points per definition are a violation of Markov Perfect Equilibria. (Maskin & Tirole) Furthermore, pure strategies in which one of the players initiates price jumps are in violation of the public goods dilemma of price jump initiation. They therefore cannot be part of the non-collusive equilibria covered in the course of this thesis.

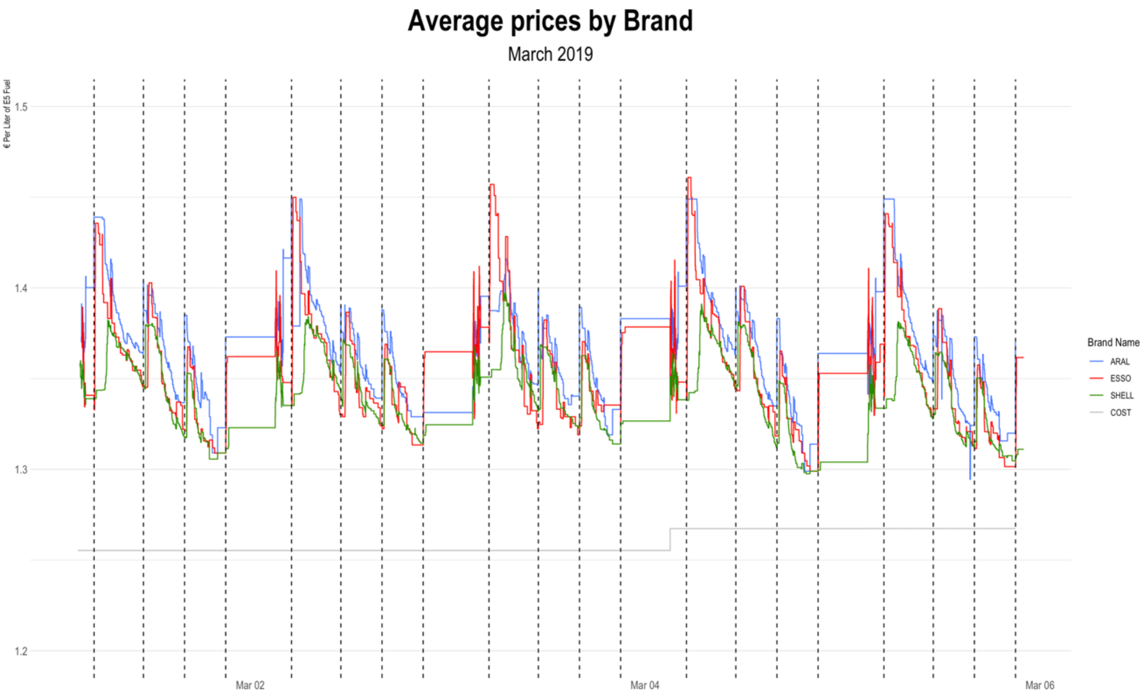

Figure 14: Colored lines represent average price by brand by minute as is the case in the previous figures, whereas the dotted vertical lines represent focal points in time. Each day there are four focal points: 08:00am, 12:00pm, 17:00pm, 22:00pm. The vertical lines are set to these hours each day. The distinction between days can be seen in the grouping of the vertical lines.

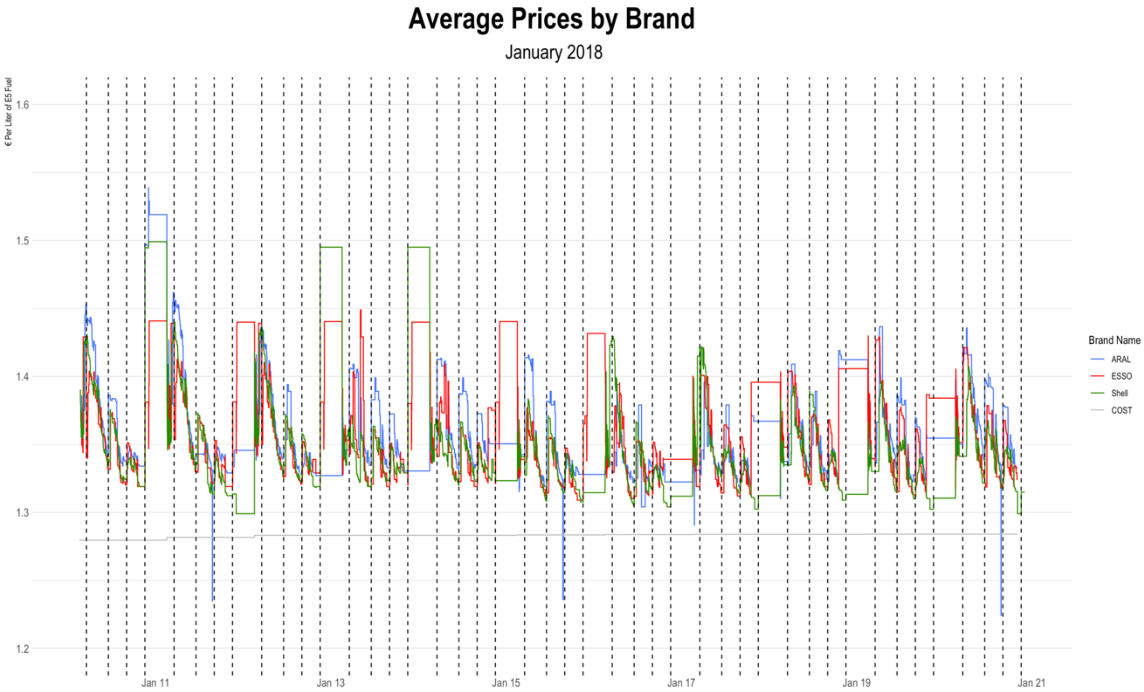

Figure 15: Same as Figure 14. Note the consistency of the timing in the price jumps. The NPJs are initiated at the focal point at 10 pm each day.

Given that both DPJs and NPJs exhibit features that are inconsistent with non collusive equilibria in mixed strategies, it seems unlikely that the pricing patterns found in the German retail gasoline market from 2017-2019 were indeed Edgeworth cycles sustained by a mixed strategy equilibrium. While the shape of the DPJs may be reminiscent of Edgeworth cycles, it is the consistency and the timing in which the price jumps are initiated and not the shape of the undercutting phase that hint towards collusive behavior.

Conclusion

The main goal of this thesis is to determine, or at least exclude, specific equilibrium concepts as the driving force behind the pricing patterns in the German retail gasoline market. The literature on the German retail gasoline market such as Linder (2018) and Cabral et Al. (2018) mainly offers two concepts, Markov Perfect Equilibria and collusive equilibria.

To test the hypothesis on whether the pricing patterns are sustained by collusive equilibria, I bifurcate the thesis into a theoretical as well as an empirical part. The goal of the theoretical part of this thesis is to determine if non collusive equilibrium concepts can be excluded from the German gasoline market a priori due to a mismatch between the assumptions of the theoretical models on non-collusive equilibria and the reality in the market. The second reason for this theoretical analysis lies in determining possible differences between collusive and non-collusive behavior. Specifically, behavior that is mutually exclusive with either equilibrium concept is of special interest for the second part of the thesis, the descriptive empirical analysis.

The goal of the empirical part is to identify whether the actual behavior of firms in the market contradicts non-collusive behavior. I observe the average price by brand from 2015 to 2019 I Hamburg, Germany. Given the absence of agreements in non-collusive equilibria, changes in patterns and the subsequent reaction of the remaining firms in the market are analyzed. Furthermore, given the reliance on mixed strategy equilibria in non-collusive models such as that of Maskin & Tirole (1985), the persistence and repetitiveness of the daily pricing interactions between firms is monitored.

While the theoretical part of the analysis leads to the conclusion that non-collusive equilibria cannot be excluded as a possibility in the German gasoline market, the behavior of the firms in the market casts doubt on the idea that the pricing patterns therein are not sustained by collusion. The existing models in the literature on cyclical pricing behavior, as well as the extension thereof in this thesis, rely on the concept of mixed strategy equilibria. The high consistency in the timing as well as the reliability of the price jumps leads to the conclusion that the actual patterns in the German retail gasoline market would be in contradiction to these equilibria. Furthermore, the interruption of a long-standing pattern in the market and the subsequent reaction by the competitors in January 2018 indicates the breach of a collusive agreement. These empirical findings lead to the conclusion that the pricing cycles in the German market were indeed sustained by collusion.

The implications of the findings are double edged. On the one hand, antitrust authorities may at least have the possibility to disprove the existence of Markov Perfect Equilibria, or derivations thereof to be behind the patterns in the German retail gasoline market. This therefore raises the question as to how such equilibria may have been coordinated. As pointed out by Byrne & DeRoos (2019) in the Australian market, implicit collusion may be harder to prosecute than its explicit counterpart. In the German context, Peters (2022) argues that the German antitrust law suffers from blind spots regarding implicit collusion in the context of the retail gasoline markets. While the focus of this thesis lies in proving the existence of collusive equilibria, the mode of communication of these agreements, i.e. if they are explicit or implicit, has not been established. As such, further research is required to determine the instrument of coordination.

The question however remains with respect to the outlook for policymakers. For instance, Wang (2009), analyzes the effect of introducing legislature that forces retail gasoline stations to make simultaneous pricing decisions in Australia. Edgeworth cycles cannot exist in a market with mandated simultaneity in pricing. However, as is shown by Byrne & DeRoos (2019) in the Australian market a few years later, collusive pricing cycles can even be coordinated in markets with mandated simultaneous pricing. As such the question remains on the long-term efficiency of mandated simultaneity as a tool for policymakers, especially if the pricing cycles in the German retail gasoline market are unlikely to be related to Edgeworth cycle behavior as of Maskin & Tirole (1988).

On a more positive note, while it was not in the scope of this thesis to legally prove collusion in the German retail gasoline market, this thesis may at least deliver some additional evidence against the existence of Edgeworth cycles, which may be used as a convenient disguise for collusive behavior.

References

Assad, S., Clark, R., Ershov, D., & Xu, L. (2020). Algorithmic pricing and competition: Empirical evidence from the German retail gasoline market.

Bantle, M., Muijs, M., & Dewenter, R. (2018). *A new price test in geographic market definition: An application to German retail gasoline market* (No. 180). Diskussionspapier.

Byrne, D. P., & De Roos, N. (2019). Learning to coordinate: A study in retail gasoline. *American Economic Review*, *109*(2), 591-619.

Cabral, L., Durr, N. S., Schober, D., & Woll, O. (2018). Learning Collusion: Theory and Evidence from the Shell Price Matching Guarantee.

Castanias, R., & Johnson, H. (1993). Gas wars: Retail gasoline price fluctuations. *The Review of Economics and Statistics*, 171-174.

De Haas, S. (2019). *Do pump prices really follow Edgeworth cycles? Evidence from the German retail fuel market* (No. 13-2019). MAGKS Joint Discussion Paper Series in Economics.

Eckert, A. (2013). Empirical studies of gasoline retailing: A guide to the literature. *Journal of economic surveys*, *27*(1), 140-166.

Edgeworth, F. Y. (1925). *Papers relating to political economy* (Vol. 2). Royal economic society by Macmillan and Company, limited.

German Ministry of Justice. Gesetz gegen Wettbewerbsbeschränkungen (GWB)

§ 47k Marktbeobachtung im Bereich Kraftstoffe

Haucap, J., Heimeshoff, U., & Siekmann, M. (2015). *Price dispersion and station heterogeneity on German retail gasoline markets* (No. 171). DICE discussion paper.

Holt, T., Igami, M., & Scheidegger, S. (2021). *Detecting Edgeworth Cycles*. arXiv preprint arXiv:2111.03434.

Ivaldi, M., Jullien, B., Rey, P., Seabright, P., & Tirole, J. (2003). The economics of tacit collusion.

Legal Information Service of Austria (RIS) (2011). Preistransparenzverordnung Treibstoffpreise 2011

Linder, M. (2018). Price cycles in the German retail gasoline market-Competition or collusion?. *Economics Bulletin*, *38*(1), 593-602.

Maskin, E., & Tirole, J. (1988). A theory of dynamic oligopoly, I: Overview and quantity competition with large fixed costs. *Econometrica: Journal of the Econometric Society*, 549-569.

Maskin, E., & Tirole, J. (1988). A theory of dynamic oligopoly, II: Price competition, kinked demand curves, and Edgeworth cycles. *Econometrica: Journal of the Econometric Society*, 571-599.

Noel, M. D. (2008). Edgeworth price cycles and focal prices: Computational dynamic Markov equilibria. *Journal of Economics & Management Strategy*, *17*(2), 345-377.

Noel, M. D. (2011). Edgeworth price cycles. *New Palgrave Dictionary of Economics. Palgrave Macmillan*.

Pennerstorfer, D., Schmidt-Dengler, P., Schutz, N., Weiss, C., & Yontcheva, B. (2020). Information and price dispersion: Theory and evidence. *International Economic Review*, *61*(2), 871-899.

Peters, F. (2022). Implizite Kollusion im Lichte der Tankstellenmärkte - Defizite im europäischen und deutschen Kartellrecht. University Library of the University of Heidelberg, http://www.ub.uni-heidelberg.de/archiv/31786.

Tadelis, S. (2013). *Game theory: an introduction*. Princeton university press.

Wallner, K. (1999). Sequential moves and tacit collusion: reaction-function cycles in a finite pricing duopoly. *Journal of Economic Theory*, *84*(2), 251-267.

Wang, Z. (2009). (Mixed) strategy in oligopoly pricing: Evidence from gasoline price cycles before and under a timing regulation. *Journal of Political Economy*, *117*(6), 987-1030.