Master's Thesis

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A review of the identification of market power in the liberalized electricity markets

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Abstract

The liberalization of the electricity market aimed to promote competition, innovation, and fair pricing for consumers. However, as with any imperfect system, certain loopholes exist. Some major players in the electricity market have taken advantage of these loopholes to benefit from their market power. This research examines various methods for detecting market power in the liberalized electricity market and proposes a combination of detection methods that effectively address the issue of market power abuse.

Two approaches to market power detection were identified and analyzed. The first approach involves the use of structural indices and analysis, including Concentration Ratio (Crn), Herfindahl-Hirschman Index (HHI), Pivotal Supplier Indicator(PSI), Residual Supply Index(RSI), Structure Conduct Performance Model, and Residual Demand Analysis. The second approach utilizes simulation models such as Linear Optimization, Supply Function Equilibrium, Cournot-Nash Framework, Agent-Based Model, and New Empirical Industrial Organization.

The research findings indicate that combining market simulation approaches, such as the linear optimization model, with other methods like residual demand analysis, concentration ratios, and agent-based models, provides a comprehensive approach to market power detection. The linear optimization model can identify potential discrepancies by comparing marginal costs and prices, thereby indicating possible market power abuse. By incorporating residual demand analysis, a deeper understanding of the demand side of the market can be gained. Additionally, considering concentration ratios and employing agent-based models to capture strategic choices and behaviors of market participants can enhance the accuracy of market power detection.

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Glossary

CRn Concentration Ratio

HHI Herfindahl-Hirschman Index

PSI Pivotal Supplier Indicator

RSI Residual Supply Index

ISO Independent System Operator

SCP Structure Conduct Performance

SFE Supply Function Equilibrium

ABM Agent Based Model

GenCo Generating Company

DemCo Demand Company

CUST Customer Agent

TransCo Transmission Company

NEIO New Empirical Industrial Organization

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1. Introduction

The current energy market has been placed in a dilemma requiring tackling at its roots the utilization of market power to influence the electricity price in the liberalised energy market. A liberalised energy market is one which has incorporated competition between the major players with an aim of reducing operations cost through innovation and thereby also reducing the price of electricity for consumers(Fabra et al., 2022). Market power is a known strategy used by major market players to increase the electricity market price by reducing its output or completely shutting down its asset for a certain period of time(Pham, 2019).

Before the 1990s, Liberalization of the energy market was seen as an evident way to rapidly increasing the economic growth of a nation through its privately owned players, hence not only relieving the government of the responsibility that comes with having a monopolized market system with no competition which of course had many underlying hurdles which results in the formations of regulations to reduce to enable transition in market price and eliminate the its own monopolist power(Vasilica Rotaru, 2013). Before liberalization, energy market operated as a vertically integrated system in which one market player carried out the entire lifecycle process of energy production, transportation distribution and supply to the consumers. Whereas liberalization brought about a division of the different lifecycle process for energy production and distribution in what is called a market based system, thereby preventing a single player from acquiring a significant share in the energy market and hence fostering competition between the market players with an aim of reducing the price of electricity to its marginal cost(Vasilica Rotaru, 2013). This was seen by the regulators as an efficient way to promote advancement in the energy sector while also catering for the welfare of the consumers of this energy products. In a liberalized market, a single company cannot produce, transport, and distribute electricity, this is because they would have a big market share in the energy market and would be able to use their monopolist power. Hence, liberalised market was a way prevent this from occurring. However, this shift to a market-based system had some predetermined uncertainties such as, use of market power, also, previous experience from countries operating a in a liberalized energy market showed that market do not naturally produce competition (Pham, 2019).

Electricity is a unique product that cannot be stored or substituted as at when needed and has a varying cost depending on its production (Vasilica Rotaru, 2013). In the developed countries such as countries in the European Union, the demand for electricity is inelastic, that is, irrespective of whether there is a rise or fall in the price of electricity, it demands will always remain constant (Vasilica Rotaru, 2013).These sets of unique traits of electricity enables easy manipulations of the market price via the use of market power. This use of this market power often results in rendering the existing market system inefficient, making policies and regulations based on fake market price, and the negative economic impact on the citizens as well as promoting investment § on fake values(Pham, 2019).

These manipulations of market prices have caught the attention of the government agencies and many researchers and works have long begun on how to identify the use of market power. This project will be taking a view at the established methods of detecting the use of market power and identifying the best options to be implemented.

1.1 **Research Objective**

The objective of this research is to examine the various available options for detecting the use of market power and identify the best options to be implemented.

2. Market Power - Definition

Market power is seen as the ability of a market player to increase the electricity price in the electricity market by either withholding its energy supply from the day ahead market or bidding higher prices to profitable shift the demand supply curve. This makes detecting a bit more complicated because the firm exercising market power is not necessarily the one setting the market price(Pham, 2019). For instance, a market player owning solar, wind and combined cycle gas plants may choose to withhold its asset with the highest operating cost which is the combined gas plant whereas other firms will still have to bid and cover up the left-over demand from the combined cycle gas plant that was withheld. Another firm's combined cycle gas plant becomes a marginal plant to meet the large demand and hence making it indisposed on the energy market and sets the market price. The initial firm who exercised its market power still benefits heavily from this and its remaining asset in the electricity market will highly benefit from the increased price of electricity.

Studies have shown that market player can further utilize their market power outside of just withholding assets as they can still withheld energy on the spot market(Fabra et al., 2022).

The spot market is a market system where electricity is traded for real time delivery instead of future deliveries as in the day ahead market(Shah et al., 2022). The demand and supply at the time of purchase determines price. This is being introduced to create a balance between insufficient or excessive energy production. However, the price of the spot market has an impact on the day ahead market. A rise in the price of electricity in the spot market could lead to an increase in the price of electricity in the day ahead market and likewise, a drop in the price of electricity in the spot market could equally lead to a decrease in the price of electricity in the day ahead market.

2.1 Impact of Market Power Utilization in the Liberalized Electricity Market

The utilization of market power in the liberalized electricity market can have varying impacts on the overall market system. Some of these impacts have been discussed here.

1. Increased electricity Price: Exercising market power in the liberalized energy market can lead to higher price for electricity consumers. As earlier discussed, this could be done by the withholding of energy asset by a major market player and thereby driving up market price for all producer whereas the consumers are left to handle the increased price.
2. Reduced Reliability: As these major market players can extract excessive profit from the energy market through their market power, they may be unwilling to make new investments in infrastructures that is necessary to sustain the reliability of the energy system as the introduction of market power eliminate competition from the entire system. This could in turn result in an overall less reliable energy system.
3. Reduced Competition: In the liberalized market where competition is supposed to be the main drivers of market outputs, the Introduction of market power tends to reduce this competition. Withholding energy assets means less quantity of electricity available for supply whereas the demand remains constant thus reducing competition and driving up price for consumers. This reduced competition may also result to redundancy in innovation as major and minor player may have no incentive to innovate in order to reduce their Capex & Opex cost because they have excessive profits due to the abuse of market power.
4. Reduced Efficiency: This distortion of electricity price due to abuse of market power can cause the inefficiency of the entire market system as inefficient investment

decision are being made based on wrong price signals, less incentive to invest in few technological development and as explained previously, when the innovation is reduced due to lack of incentive, the energy system could become retarded as the system is not being improved by new innovation and overtime leads to inefficiency.

2.2 General Procedures for Market Power Mitigations

The impact of market power in the liberalized electricity market has been seen to be very diverse as it affects not only the entire energy system but also the social welfare of the people.

In the liberalized electricity market, regulations are necessary and created to ensure that the efficient market operations is not compromised and to prevent market players from engaging in activities that could be detrimental to the electricity market. Rules such as bidding in good faith is commonly used, but additional measures are often implemented to specifically prevent the use of market power. These procedures can be categorized into two namely the ex-ant and the ex-post, the ex-ant procedures set rules that prevents firms from exercising its market power, these measures can be structural, limiting market share or prohibiting specific conduct. The ex – post procedures assess historical information to know if market power has been used in the past, this is also followed by rules and principles that market players must follow or prohibited conducts(Kemp et al., 2018).

There are trade-offs between using ex-ante measures, which may overly restrict behaviour and introduce inefficiencies and ex-post measure, which can be costly and contentious without specific conduct rules. The appropriate balance between these measures depends on various factors, so there are no general principles that can be applied across jurisdictions. Regulators can be prescriptive in mitigating market power. Depending on their risk preferences. Prescriptive measures risk inhibiting conduct that may not be harmful, while less prescriptive measures risk allowing harmful market power to go undetected. Policymakers must weigh the trade-off between false positives and false negatives when deciding how to mitigate market power. However, prescriptive, and less prescriptive measures can complement each other, and in many jurisdictions, a mixture of prescriptive conduct rules and standard anti-trust legislation is used to curb undesirable behaviour and prevent power abuses(Kemp et al., 2018).

3.0 Review of the Methods of Identifying market power.

Two main categories of market power detection have been established by (Pham, 2019) and one of them is the structural approach which links the lack of competition between players in the electricity market to the amount of market shares held by a key market player. The main goal of this approach is to identify potential abuse of market power by market players holding a dominant market share and then determine if any actions need to be taken to promote competition and prevent any shift to a monopolist market structure. This is a preventive measure in market power identification.

The second category mentioned by (Pham, 2019) which is the market simulation / estimation approach focuses on how much power a market player exercises in the electricity market. So, while the first approach focuses on the potentials of a firm to exercise market power, the second focuses on the how much of this power has already been exercised in the liberalized electricity market and who is responsible. This approach uses varying simulation and estimation models to analyse market behaviours and predict how changes in market conditions such as price change or entry of a new competitor may affect market outcomes. This approach stimulates how a given market may behave under different conditions. Once this has been established and markets changes in real time, market coordinators can now easily identify the source of market power and make decisions on enhancing competition and protecting the integration of the market as well as the welfare of the consumers.

Table 1: Breakdown of Market Power Detection Approaches (Pham, 2019)

Market Power Detection Method	**Structural Indices and Analysis**	**Simulation Models**
1.	Concentration Ratio and HHI	Linear Optimization
2.	Pivotal supplier indicator (PSI) and Residual supply index	Supply Function Equilibrium
3.	Structure conduct performance model	Cournot-Nash framework
4.	Residual Demand Analysis	Agent based model
5.		New empirical industrial organization

3.1 Structural Indices and Analysis

3.1.1 The Concentration Ratio (CRn) and the Herfindahl-Hirschman Index (HHI)

(Pham, 2019) stated that Mason's structure conduct performance (SCP) approach which was introduced in 1930s by a Harvard scholar was the initial effort to conduct an empirical analysis of market power. The declaration made is that the performance of industry is subjected to the actions of its buyers and sellers which are in turn influenced by the market structure. The market structure is commonly described by the concentration ratio of firms market shares or Herfindahl – Hirschman Index(HHI) which measures the relative market shares of the largest firm.

The concentration ratio (CRn) and Herfindahl – Hirschman Index (HHI) are known methods for analysing market concentration. They are used in analysing the degree of competition in a market by measuring the market share of the largest firms in the market.

The concentration ratio (CRn) is a method of measuring market concentration by measuring the combined market share of the largest n firms in a market. For example, three(3) firm concentration ratio (CR3) would measure the combined market share of the top 3 firms in the market. The higher the concentration ratio of these firms, the more concentrated the market and less competitive it is. The concentration ratio provides an indication of the degree to which a market is dominated by a small number of firms. (Pham, 2019) stated that a market is said to be concentrated when its concentration ratios CR1, CR3, CR5 exceeds 33.3%, 50% and 66.7%. For example if the CR3, a three(3) firm concentration ratio for the Spanish market in the offshore wind segment exceeds 50% or maybe is at 65%.

This means that these three firms control all the market shares in the offshore wind in Spain and hence the Spanish offshore wind segment is highly concentrated, and these 3 largest firms have a significant market power that they could exercise. However, (Pham, 2019) stated that the concentration ratio (CRn) methods is a poor measure of market concentration in the electricity market as it ignores the demand side of the market but it is efficient is identifying presumed locations where market power could be utilized.

The Herfindahl – Hirschman Index (HHI) is another method of measuring market concentration. It takes into consideration both market concentration and the number of firms operating within a market, by factoring the market share or relative size of each firm. It is calculated by squaring the market shares of each firm in the market and summing the values (Rhoades, n.d.). The formular for HHI is shown as follows:

$$HHI = \sum_{i=1}^{n} (MS_i)^2$$

Where MS_i is the market share of firm I and n is the number of firms in the market.

For example, assuming there are 4 energy providers in the offshore wind farm market in Spain. Energy provider 1 has 30% of market share, energy provider 2 has 25%, energy provider 3 has 20% and energy provider 4 has 25%. For this example which is an unreal case in Spain, the HHI can be calculated as follows.

$$(30)^2 + (25)^2 + (20)^2 + (25)^2 = 2{,}550$$

(Rhoades, n.d.) stated that if a few firms have high concentration hence dominating the market, the HHI will be high and there might be less competition in that market. Also, if there are many firms with low concentration, the HHI will be low and competition is likely to be strong. A monopoly will exist when one firm controls 100% of the market shares and hence having a HHI value of 10,000 which is the maximum (Rhoades, n.d.). If the HHI surpasses 1000 points, market is concentrated.

Table 2: Shows the Concentration for Critical Levels(Chr Matthes Sabine Poetzsch Katherina Grashoff & Head Office, 2005)

Concentration Ratio **CRn**	**Herfindahl – Hirschman Index** **HHI**
Market is said to be concentrated if; **CR1 > 33.3%** **CR3 > 50%** **CR5 > 66.7%**	Unconcentrated: HHI < 1,000 Moderately concentrated: 1,000 < HHI < 1,800 Highly concentrated: HHI > 1,800

3.1.1.1 Barriers of CRn & HHI for Market Power Detection

Market segmentation: This is the division of markets into various segments based on different characteristics such as product type, geographical location, customers, etc. There are various segmentations in the liberalized wholesale electricity market in Europe. They include the following:

a. Day ahead market: This is a market where electricity producers and consumers bids for electricity for the next day.
b. Real time Market: As the name implies, here electricity is sold and bought for the present day.
c. Balancing Market: This is a market used to balance supply and demand in real time. Here, electricity generators and retailers trade electricity to create a balance between demand and supply of electricity.
d. Capacity Market: The capacity market is used to incentivize power producers to invest in additional capacity to ensure grid reliability. In these markets, electricity producers can bid for power supply rights during periods of high demand. These markets may also have varying degrees of concentration and market strength.

Interactions between segments: These are interdependencies between different segments of the electricity market whose outcome may influence the outcome of another segment since the various segments are interconnected. The various segments such as day ahead market, real time market, balancing market and capacity market in the liberalized electricity market are interconnected and may affect each other.

For instance, the results of capacity auctions which are conducted in the capacity market can impact the prices in the day – ahead market. This is because capacity auctions determine the electricity generations available for sells in the market and which then affects the supply of electricity in the day ahead market. If there is an increase in available generation capacity due to successful capacity auction, then there will be an increase in the supply of electricity in the day ahead market and hence a decrease in prices of electricity. However, if the reverse happens and the capacity auction is unable to secure enough available electricity generation, then the supply of the electricity in the day ahead market will decrease, and this will cause an increase in prices.

The balancing market can also influence the prices in the day ahead market because the balancing market is used to ensure that there is a balance between demand and supply in real time. If there is a high demand for electricity in the balancing market, the price of electricity in the balancing market will increase leading to a price increase in the day ahead market. Whereas, if the demand for electricity in the balancing market is low, the price of the electricity in the balancing market will decrease and this can lead to decrease in the price of electricity in the day ahead market.

Therefore, it is challenging to use the concentration ratio (CRn) and Herfindahl-Hirschman Index(HHI) to measure concentration and identify market power in the liberalized electricity market without taking into account the interactions between segments. Ignoring the interdependencies between the different segments can lead to an incomplete understanding of market power and concentration levels in the wholesale electricity market. To accurately measure concentration and identify market power in the liberalized electricity market, it is very important to consider the interaction between all the various segments reinforcing the market and their influences on each other and this may be quite complicated using the CRn and HHI measures and as such may not be considered as the best option in identifying market power in the liberalized electricity market.

Dynamic Market Conditions: The liberalized electricity market in Europe is highly dynamic and are subjected to changes due to weather conditions, demand and supply, technological advancement, energy policy and many other factors. As such, it may be difficult using Indexes like CRn and HHI to identify market power in real time as they do not capture the changes in the market in real time. For example, if a hydropower plant blanks out and is unable to supply electricity due to some problems, the electricity supply in the market would be significantly reduced. In this case, other electricity generators will have the ability to increase price if they choose to and hence leading to the exercise of market power. This sudden changes in market condition makes it difficult to use the CRn and HHI to identify market power in real time in the liberalized electricity market.

Another example of the dynamic market conditions of the liberalized electricity market is the weather conditions. For instance, during hotter or colder seasons, the demand for electricity will drastically increase for either heating or cooling and this will in turn affect market concentration and market power in the liberalized electricity market. Electricity generators with excess capacity may decide to increase prices, hence utilizing market power, this is because the supply of electricity may not be enough to meet demand and electricity generators with excess electricity supply may decide to take advantage of the situation and increase the prices. Also, an increase in the available renewable energy supply such as solar, wind etc would lead to a decrease in price of electricity and thus reduces the occurrence of market power and vice versa.

In summary, the liberalized electricity market is always changing as it subjected to dynamic conditions which makes it very challenging to use the CRn and HHI to identify market power in real time. As (Pham, 2019) stated, the HHI and CRn do not consider the demand side of the electricity in its measurement and hence makes the measurement inefficient and unreliable.

3.1.2 Pivotal supplier Indicator (PSI) and Residual Supply index (RSI)

PSI and RSI are indicators that were developed specifically for the electricity market by the California Independent System Operator (ISO) in 2002. These indicators consider the demand side of the electricity market when analyzing and this distinguishes them from the traditional concentration Indexes. PSI is a binary indicator that assesses whether a supplier is necessary to meet the demand. If the supplier can meet demand the PSI is 1 and the supplier is considered as pivot and may be seen to possess market power whereas, if the supplier is unable to meet demand, PSI is 0 and the supplier does not possess market power. RSI is a ratio that measures the residual supply relative to the total demand. If RSI is above 100%, other suppliers have enough capacity to meet demand, this reduces the influence of a supplier on the market price (Pham, 2019). However, If RSI is below 100%, the supplier becomes crucial in meeting demand and can set the price as high as the price cap allows. (Pham, 2019) stated that the indicators can be computed for every hour and for every firm and a supplier is consider pivot if the PSI is 1 for over 20% of the hours or if RSI is less than 110% for more than 5% of the total number of hours in the year, meaning that the supplier is necessary to meet the demand in a significant proportion of the time which indicate a high level of market power.

Mathematically, the PSI can be represented as follows.

PSI_t^i= I($D_t - C_t^{Tot} + C_t^i$) (Hesamzadeh et al., 2011)

Where;

PSI = Pivotal supplier Indicator

i = Generating firm

t = time

D_t = geographical region

C_t^{Tot} = Imported capacity

C_t^i = Generator capacity

If PSI = 1 ; Supplier is pivotal and holds market power, If PSI = 0, Supplier is not Pivot and does not hold market power

Similarly, the RSI can be represented as follows.

$RSI_t^i = \frac{C_t^{Tot} - C_t^i}{D_t}$ (Hesamzadeh et al., 2011)

If RSI < 100%; supplier is crucial in meeting demand and can set high market price.

If RSI > 100%; capacity is distributed amongst other supplier and no one supplier is pivotal to meet demand.

(Hesamzadeh et al., 2011) further stated that the Pivotal supplier indicator and the Residual supplier indicator do not consider the transmission constraints in the electricity market, and this has a great impact on the market power. This will be further explained in the section of PSI and RSI barriers.

3.1.2.1 Barriers of PSI & RSI for Market Power Detection

PSI & RSI have numerous barriers for the identifying of market power in the liberalized electricity market and in this section, some of the barriers will be discussed.

To compute PSI and RSI, it is very important to have a detailed data on the supply and demand conditions of the electricity market which includes the capacity of each supplier, the amount of energy demanded and the market price at various times in the market. However, in the European electricity market, data may not be readily available due to some constraints. This is because there are strict regulations placed to protect the privacy of customers data and this places a limitation of the amount of data that can be obtained, secondly, there may be challenges relating to data access and sharing among different players in the electricity market and this could further limit the access to data.

Limited access to data can affect the reliability and accuracy of the PSI and RSI indicators in identifying market power as if the data used to compute the PSI and RSI are incomplete or incorrect, the results may not reflect the actual market condition and may lead to incorrect conclusions about the presence of market power. For example, if the data used to calculate the residual supplier indicator does not account for the available capacity of all suppliers, the result may overestimate the market power of a specific market supplier.

Moreover, limited data availability can also affect the comparability of the results across different markets and time periods. If the data used to calculate the indicators is not consistent across different markets or time periods, the results may not be directly comparable, which can limit the usefulness of the indicators in identifying market power trends and patterns. For example, if different data sources or different data collection methods are used, this may result in different values for the PSI and RSI indicators, which could lead to inaccurate comparisons across different markets or time periods.

Another barrier is that the PSI and RSI do not account for transmission network constraint. In the European electricity market, a transmission constraint can restrict the amount of electricity transported across various segments of the grid. What this means is that a dominant supplier in one part of the grid may not be able to exercise the same degree of market power in any part of the grid due to transmission constraints. The PSI and RSI do not account for these transmission constraints but focuses on only the demand and supply side of the electricity market and as such these indicators may not accurately reflect the extent of market power a certain supplier has in the liberalized electricity market and thus leading to incorrect conclusions on market power.

3.1.3 Structure Conduct Performance Model (SCP)

The Structure Conduct Performance (SCP) model is an econometric framework that can be used to analyze the relationship between market structure, firm conduct, and firm performance in the electricity market. The SCP model seeks to identify how changes in market structure, such as increased concentration or vertical integration, affect the behaviour of firms and their performance outcomes. In the electricity market, the market structure is its characteristic that affects firms behaviour operating within it. This includes characteristics such as degree of vertical integration(the extent to which firms are involved in multiple stages of the electricity supply chain such as generation, transmission, distribution), number of firms in the market, the concentration level(the degree to which a market is dominated by a number of firms). The characteristics of the market structure can affect the competition level in the market and the ability of firms to exert market power. (Yong, 2016)

Firm conduct is the behaviour of individual firms operating withing the market and this can be influenced by the market structure. This may include variables such as pricing strategies, investment decision and these variables influence the competitiveness of individual firms and their ability to succeed in the market.

Firm performance is the accomplishment by individual firms operating within the market and this is influenced by both the market structure and the firm conduct. Firms' performance may include the firms profitability (i.e the level of profits generated by firms), market shares, customers satisfaction. These variables provide insights into the competitiveness of the market as well as the efficiency of individual firms.

Using econometric analysis, the SCP model can be used to identify the relationship between market structure, firm structure, and performance. For instance, if the model shows that increased concentration in the electricity market leads to higher prices and lower consumer surplus, it may indicate that a few firms are dominating the market and exercising market power which allows them to influence the market price and reduce the overall welfare of consumers. The SCP methods focuses on identifying the factors that contributed to the use of market power (Pham, 2019). This could involve analysing variables in the market structure such as concentration levels, degree of vertical integration and firms conducts such as pricing strategies.

3.1.3.1 Barriers of SCP for Market Power Detection

SCP depends on structural indexes such as Concentration ration (CRn) and as previously explained these indexes have certain limitations when used in the electricity market. (Pham, 2019) stated that after analysing firms' performance using rate of return, price average cost margins and price marginal cost margins, weak links were found to exist between concentration and firms' performance. This means that there is little or no correlation between market concentration and the firms performance. A highly concentrated market does not automatically lead to a better or worse firm performance. This jeopardizes the SCP model for market power detection as the model tries to identify the cause of market power through concentration and other market structures and their links to the firms conduct and firms' performance.

Secondly, SCP model for detecting market power requires data on market structure, firm behavior, and firm performance to determine the relationship between these variables. However, obtaining high-quality data on these variables can be difficult in a liberalized electricity market. Data on market structure may not be available or may be incomplete, making it difficult to accurately measure concentration or the degree of vertical integration in the market. Similarly, data on business behavior, such as pricing strategy, investment decisions, can be difficult to obtain or of poor quality, making it difficult to accurately analyze the relationship between market structure and firm behavior. Data about a company's performance, such as profitability, market share and customer satisfaction, can also be difficult to collect or can be biased or misreported, further complicating economic analysis. Therefore, the collection of accurate and reliable data on market structure, business behavior and business performance are crucial for effective use of the SCP model in detecting market power in the liberalized electricity market.

Furthermore, the electricity market is extremely dynamic and constantly changing in response to new technologies, economic advances or its reverse and changes in policies (Fabra, 2001). SCP relies on historical information to create a link between market structure, firm conduct and performance in order to identify the presence of market power. Since the liberalized electricity market is dynamic, historical data may not be a reliable source of information for the current market conditions and of course will not accurately capture the behaviour of firms.

For example, technological advances in renewable energy sources such as solar and wind are changing the mix of energy sources and demand patterns, significantly impacting the electricity market. Similarly, economic factors such as changes in fuel prices and economic growth can affect the demand and supply of electricity, as well as the market structure and pricing behavior of firms.

Political changes, such as the introduction of carbon pricing mechanisms and subsidies for renewable energy, can also have a significant impact on electricity markets, influencing corporate behavior and altering market structures.

Due to these factors, historical data may not accurately reflect current market conditions and it may be difficult to predict future market results. To meet this challenge, market analysts may need to consider different scenarios and use advanced modeling techniques that can account for the dynamic nature of electricity markets. This may involve incorporating real-time data and using advanced modeling tools such as artificial intelligence and machine learning.

The SCP model assumes that market structure is exogenous, that is, it is determined independently of firm behaviour or market outcomes. In other words, the SCP method assumes that the structure of the market is fixed and beyond the control of the firms operating in the market. However, in a market as dynamic as the electricity market, firm behaviour and changes in market outcomes can affect the market structure, making it endogenous. For example, if a dominant company practices predatory pricing to drive competitors out of the market, it can increase its market share and concentration, which will ultimately affect its market share. Likewise, changes in market conditions such as the entry of firms or changes in regulatory policies can also affect market structure. The endogeneity of this market structure can complicate the use of the SCP method to detect market power. If market structure is not exogenous, then any relationship observed between market structure and firm behaviour or performance may not be causal. In such a case, it can be difficult to pinpoint the presence of market power or discern the impact of market structure and firm behaviour on market outcomes.

Therefore, in a market as dynamic as the electricity market, it may be necessary to adopt more flexible approaches that can take into account the endogeneity of the market structure and be able to capture complex interactions between market structure, firm behavior, and market outcomes over time.

Another problem is that in SCP studies, cost price margins is used as a measure of a firm's performance, which is the difference between the price a company charges for its product and the average cost of producing that product(Pham, 2019). In order to assess the exercise of market power in the energy market, it is crucial that electricity generators bid at marginal cost (Twomey et al., 2005)

In particular, several studies compute the price-cost margin using average cost rather than marginal cost. Average cost is the entire cost divided by the total quantity produced, whereas marginal cost is the additional cost incurred by manufacturing one more unit of a good.

The price-cost margin calculation may be skewed if average cost is used instead of marginal cost. This is due to the fact that the price-cost margin determined using average cost makes the assumption that the firm's costs would remain the same as it produces additional units. Using average cost instead of marginal cost can overstate or understate the genuine price-cost margin because the company's costs may change as it produces more units.

3.1.4 Residual demand Analysis

The residual demand analysis is a method used to assess a company's level of market dominance in a specific market(Twomey et al., 2005).

After accounting for the demand and supply curves of other market participants, the residual demand curve represents the amount of a good or service that a business can sell at various prices. It is derived by deducting the demand curve for the entire market from the supply curves of all other market players. After taking into account the supply curves of all other participants, a company's residual demand curve is the demand curve for its own product. (Twomey et al., 2005).

Because it considers the actions of other market players, residual demand analysis is seen as a more complex way to assess market power than other measures like CRn and HHI. By looking at the residual demand curve of a company, we may more clearly comprehend a company's ability to wield market power. However, the analysis is done ex-post, that is after the electricity generators has already submitted their bids, so the residual demand curve is not known in real time, however, this data for constructing this residual demand curves are available.

Demand elasticity, which describes how responsive consumers are to price changes, is taken into consideration by the residual demand curve. Demand will decrease significantly with a little price rise if it is relatively elastic, and vice versa. Demand will only slightly decrease with a significant price increase if it is somewhat inelastic, and vice versa. The amount of market power a company has is indicated by the residual demand curve slope at its output level. If the slope is steep, it indicates that the firm has a lot of market power since it can raise prices without seeing a big drop in demand. The corporation may have less market control if the slope is shallow since it must keep its pricing relatively low to retain demand. The slope of a company's residual demand curve is infinite if it is pivotal, which means it is the only provider of a specific commodity or service in the market. Because there are no other suppliers, the business can establish any price it likes for the crucial quantity of demand. Compared to businesses in more competitive marketplaces, pivotal firms frequently have the ability to charge higher prices and make bigger profits (Pham, 2019)

3.1.4.1 Barriers of Residual Demand Analysis for Market Power Detection

For residual demand analysis, bid data is typically accessible, but it might be difficult to collect complete and reliable data. The complexity of the energy market, which might include numerous layers of regulation and market rules that make it challenging to collect the essential information, is one reason for this, as I previously indicated. The unwillingness of market participants to exchange information also contributes to the limited availability of bid and offer data.

The difficulty in receiving accurate and comprehensive information on market transactions, including bids, offers, and market results, is referred to as a lack of transparency in the energy market. The performance of residual demand analysis, which uses bid data to build the residual demand curve and assess the exercise of market power by producers, may be hampered by this lack of openness (Joskow, 2006). The complexity of the electrical industry is one factor contributing to the lack of transparency. Market regulations frequently consist of several tiers, including those set by market operators and grid operators as well as federal, state, and local laws. It may be challenging to collect the information required to do residual demand analysis because of these regulations (Crampton, 2003). The unwillingness of market participants to provide data is another factor contributing to the lack of transparency. For instance, generators might be reluctant to disclose specifics about their bids and offers if they fear disclosing confidential information or coming under regulatory investigation.

Overall, doing residual demand analysis and keeping an eye on market power might be difficult due to the lack of transparency in the energy market. To overcome these obstacles, researchers and regulators have proposed a variety of strategies, such as requiring more data disclosure from market participants or using alternative data sources, including electricity flow statistics, to forecast market outcomes (Wolak, 2003).

It might be difficult to determine the residual demand curve, especially if it is done hourly. Additionally, it necessitates a precise description of the pertinent market, which can be challenging to establish in practice given how intricate energy markets are. These elements can make it difficult to use residual demand analysis in practice(Pham, 2019).

Residual demand analysis may be less successful in identifying market power in situations when there is a significant level of market concentration. This is due to the fact that there are less independent market participants, which makes it simpler for generators to coordinate their bids and exploit market power covertly. To determine market power under such circumstances, alternative techniques like market simulation or econometric research may be required (Fabra et al., 2022)

By altering the elasticity of the residual demand curve, transmission restrictions can reduce the accuracy of residual demand analysis. The demand for electricity that remains after the demand from load-serving entities has been satisfied is represented by the residual demand curve (Crampton, 2003). There are two ways that transmission restrictions can lessen the residual demand curve's flexibility. First, they might make it harder for power to move between regions, which might lead to price variations. This could lead to a less responsive demand curve for each distinct location, which lowers the residual demand curve's overall elasticity (Wolak, 2003). Second, transmission limitations may result in a reduction in the total amount of generation capacity in a given area. When this happens, the residual demand curve could move to the left, representing less capacity that is readily available and a more expensive equilibrium price. The residual demand curve's elasticity may be lessened by this change, and this would increase the possibility of using market power (Joskow, 2006).

In areas with confined or inadequate transmission capacity, these effects are particularly noticeable. These regions may have residual demand curves that are less sensitive to supply changes, which could make it simpler for generators to increase prices and exert market control. Since transmission constraints were not factored into the residual demand curve analysis, using this curve could result in underestimating the degree of market power(Pham, 2019).

3.2 Market Simulations/ Estimation Approaches

This model considers market power to be an unknown component that must be evaluated, whereas SCP studies concentrate on what creates market power with the assumption that the quantity of this market power is known. This approach distinguishes itself by calculating marginal cost and identifying oligopoly equilibria in various wholesale electricity markets, which goes by a variety of names and is executed using a variety of techniques ranging from the simplest to the most complex. (Pham, 2019).

3.2.1 Linear Optimization model

The quantity of power delivered by each producer in a liberalized wholesale electricity market is determined by this strategy utilizing an efficient dispatch system. In consideration of network and dynamic restrictions on the power plants, the objective is to satisfy demand while minimizing total cost of output. For each power station in the model, the dispatch system generates hourly generation and generation cost data that are reported in order of merit. The producing units are sorted according to their variable cost of production, with the least expensive unit being ranked first, in what is known as the order of merit (Pham, 2019).

With few exceptions when capacity limits apply, the system marginal cost is computed based on the variable cost of the highest generating unit during each hour to estimate the market power of the producers. This marginal cost is the additional expense incurred while producing one additional unit of electricity for the market. Ideally, the extent of market power cannot be fully known without knowing the marginal cost (Frank, 2001)

Conclusions concerning the degree of market power in the market can be made based on the discrepancy between the system marginal cost and the observed hourly prices. When the observed price exceeds the system marginal cost by a large margin, it signals that certain market participants may be abusing their market power by placing bids over their marginal costs (Frank, 2001)

To find the best bidding methods, the core idea is to create a mathematical optimization problem that encapsulates the goals and limitations of the market players. Market power can be identified by contrasting the optimal bids with the actual bids made by the market participants.

A linear programming model is a standard way to formulate the optimization issue. The objective function of the market players, which depicts their profit-maximizing behavior under a variety of restrictions, such as the market rules and regulations and the physical constraints of the power system, is often included in the model. Assumptions concerning the behavior of other market participants, such as their demand elasticity and bidding techniques, can also be incorporated into the model.

3.2.1.1 Constraint of Linear Optimization Model for Market Power Detection

The electrical transmission network must be well modeled in order to use the dispatch model for market power detection in liberalized electricity markets and produce reliable results. The dispatch model is a mathematical optimization problem that seeks to reduce the overall cost of producing energy while taking into account a variety of physical and legal restrictions, including those imposed by the transmission network. The transmission network, which links power generators to distribution networks and ultimately to end customers, is a sophisticated network of high-voltage power lines and transformers. While the capacity restrictions refer to the maximum amount of power that can be carried across each line, the network topology refers to the actual configuration of the transmission lines. The permitted range of voltage levels that can be maintained on the transmission network to guarantee safe and dependable operation is referred to as voltage restrictions.

The dispatch model needs access to accurate and current information on the network topology, capacity constraints, and voltage restrictions in order to simulate the transmission network effectively. However, the transmission network's actual operating conditions are subject to a number of uncertainties and inaccuracies, which can make it difficult to acquire correct statistics.

The topology of the network and its capacity constraints, for instance, may change as a result of alterations to the physical environment, such as the building of new power plants or the extension of current infrastructure. The flow of power and the cost of generation can also be incorrectly predicted if the network data is inaccurate or if the modeling assumptions are incorrect. Furthermore, a number of external elements, including the weather and natural disasters, can have an impact on the transmission network's performance and dependability. Extreme weather conditions, for instance, might disrupt electricity flow or induce power outages, which can result in poor dispatch decisions and increased generation costs. In order to detect market power in liberalized energy markets, correct modeling of the transmission network in the dispatch model is therefore crucial. However, it is subject to a number of uncertainties and obstacles that must be addressed in order to produce trustworthy results.

Secondly, due to technical and physical restrictions, power plants are unable to modify their output levels instantly. Instead, dynamic limitations on power plants prevent them from gradually ramping up or down their production levels. These limitations include minimum operational levels, start-up costs, and scaling rates.

Ramping rates are used to describe the fastest rate at which a power plant can change its output level over a predetermined amount of time. Start-up costs are the expenses related to restarting a power plant after it has been off-line or running inefficiently. The minimal output level necessary for a power plant to run effectively and safely is referred to as the "minimum operating level." The dispatch model's inclusion of these dynamic limitations might exacerbate the optimization problem's complexity and make it more challenging to resolve. The model must account for the limits placed on the power plants as well as the predicted future demand for electricity. The trade-off between the costs of ramping up or down power plants and the costs of producing electricity at various levels must be taken into account by the dispatch model.

Advanced optimization methods and computational tools are frequently employed to resolve the dispatch model with dynamic constraints in order to deal with these problems. These methods can be used to find the generating schedule that reduces overall production costs while meeting all of the system's physical and regulatory limitations.

3.2.2 Cournot-Nash Model

The Cournot model is a mathematical framework that is commonly used to evaluate strategic interactions among market participants, such as those in the energy market. In this model, each market participant, particularly those on the supply side, attempts to establish their ideal output level in order to maximize profit. The main challenge in applying the Cournot model to competitive energy markets is calculating an inverse demand curve that depicts the link between demand and market price. The inverted demand curve illustrates the connection between the quantity demanded by consumers and the pricing of a product or service. The inverse demand curve in the energy market represents the quantity of electricity that consumers are willing to purchase at different price levels. (Kang et al., 2005)

To derive an inverse demand curve in the Cournot model, we assume that the demand for electricity is responsive to changes in the market price. This means that if the price of electricity increases, consumers may reduce their demand for electricity, and if the price decreases, they may increase their demand. This is known as demand response to market price. Once we have an inverse demand curve, each market participant can use it to determine their optimal output level. They will try to estimate how much electricity the other participants will produce and then determine their own output level based on that estimation. The goal is to maximize their profit, which is the difference between the revenue they earn from selling electricity and the cost of producing it (Kang et al., 2005).

(Pham, 2019) explained that Cournet models could be used to estimate the equilibrium prices in a market with multiple firms and at several demand levels, meaning that different levels of consumer demand for electricity was considered. In addition to estimating the Cournot equilibrium prices, the authors also made an estimation of the price emerge if all firms were to behave as competitive price takers. This means that they assumed that each firm in the market would act as if they had no market power and would simply set their prices based on the prevailing market conditions. This is known as the competitive equilibrium price. By comparing the results of these two equilibria, the authors were able to derive a measure of market power. In the Cournot equilibrium, each firm in the market has some degree of market power because they can influence the market price by adjusting their output level. However, in a competitive equilibrium, no firm has the market power because they all assume that their actions will not affect the market price. The difference between the two equilibria indicates the degree of market power a firm possess, and this can be used to determine to what extent, firms can influence the market price. If the difference is large, it suggests that the firms have a high degree of market power and can exert significant influence over the market price. Conversely, if the difference is small, it suggests that the firms have less market power and are not able to exert as much influence over the market price.

3.2.2.1 Constraint Cournot-Nash Model for Market Power Detection

The model is built on assumptions that may not always be accurate in practice. One of the model's fundamental assumptions is that enterprises have perfect information about market conditions and the behavior of their competitors, and that they operate rationally to maximize their profits. The assumption of complete information implies that enterprises have access to all relevant market information, such as the prices and quantities produced by their competitors, market demand, and production costs. In reality, enterprises may not have complete information and may confront unknown future market conditions. This might make it difficult for businesses to make the best judgments about production levels and pricing strategies.

The assumption of rationality implies that corporations are expected to make decisions that are in their best interests based on the information at their disposal. In practice, however, corporations may not always operate rationally. They may base their decisions on personal preferences or prejudices, or they may be vulnerable to external forces that influence their decision-making process. Finally, the assumption that firms are unconstrained may not always be correct. Firms, for example, may be subject to regulatory restraints or suffer market entrance hurdles, which might limit their capacity to compete effectively. Overall, the Cournot-Nash model's assumptions provide a simplified picture of how enterprises interact in a market. While these assumptions may not always be correct in practice, the model remains a useful tool for understanding firm behavior and forecasting market outcomes. However, it is critical to recognize the model's limitations and to consider alternative models or analysis techniques when necessary.

Secondly, to predict the equilibrium levels of output and prices, the model requires data on market demand and firm production levels. In practice, however, acquiring such data may be problematic, particularly in new or emerging market such as the renewable energy market.

Historical data on market demand and firm production levels may be available in established markets, which can be used to estimate the Cournot-Nash model parameters. Such data, however, may not be readily available in new or emerging markets. This can make estimating the demand and supply functions, which are important inputs to the Cournot-Nash model, challenging. In such circumstances, assumptions regarding the demand and supply functions may need to be established based on market trends or other accessible information.

Furthermore, the data needed for the Cournot-Nash model may not be widely available. Some businesses may be unwilling to reveal their production levels or pricing strategies, especially if they are engaging in anti-competitive behavior. Because of this lack of transparency, precisely estimating the Cournot-Nash model parameters can be difficult.

Again, while data may be available in some cases, it may not be reliable or accurate. Firms, for example, may underreport their output levels to evade regulatory scrutiny or to obtain a competitive advantage. Such data quality difficulties can lead to skewed estimations of the Cournot-Nash model's parameters, which can lead to erroneous market predictions.

In summary, the Cournot-Nash model requires market demand and firm production levels, which can be difficult to attain in practice, especially in new or emerging markets. In such circumstances, assumptions must be made based on available information, and the data's quality and dependability must be carefully examined.

Thirdly, the dynamic nature of markets poses a challenge in the detecting market power using the Cournot-Nash model. The model implies that enterprises have perfect information about market circumstances and the actions of their competitors, and that they operate rationally to maximize their profits in response to these conditions. However, as market conditions evolve, the assumptions underlying the Cournot-Nash model may no longer be valid.

For example, if a new technology upsets the market, the demand and supply functions may fluctuate, as well as the competitive environment. The Cournot-Nash model may no longer adequately capture market dynamics in such instances, and market power detection using this model may need to be revised often to reflect changing market conditions. Furthermore, even if market conditions remain relatively stable, the Cournot-Nash model parameters may need to be updated on a regular basis to reflect changes in firm behavior. Firms may adjust their pricing strategy or production levels in response to changing market conditions. These behavioral changes can have an impact on the Cournot-Nash model's parameter estimates, and thus the accuracy of market power identification using this model.

In summary, the dynamic structure of markets makes detecting market power using the Cournot-Nash model difficult. The model may need to be updated often to reflect changing market conditions, and the model's accuracy may be dependent on the availability of up-to-date data and the ability to estimate the model's parameters accurately.

Another possible constraint faced by the Cournot – Nash model is the lack of transparency; the model assumes that enterprises have comprehensive knowledge of their competitors' actions and market conditions. However, if are not open about their pricing and production decisions, it can be difficult to estimate firms the model's parameters accurately. In such instances, market power detection using the Cournot-Nash model may be less reliable, necessitating the consideration of alternate methodologies. To solve concerns of market transparency, authorities and policymakers may need to take efforts to promote market transparency. They may, for example, require firms to reveal pricing and production statistics, or they may demand the use of publicly available standard pricing systems. Furthermore, advances in data collection and analysis may allow for the inference of pricing and production decisions even when firms are not transparent. However, such approaches may need to be balanced against privacy and proprietary information concerns.

In summary, lack of transparency in pricing and production decisions might make using the Cournot-Nash model to identify market power issues problematic. To overcome this issue, regulators and policymakers may need to boost market transparency or investigate alternate modeling methodologies.

3.2.3 Supply Function Equilibrium Model

The concept of supply function equilibrium (SFE) is a modeling approach devised by Klemperer and Meyer to analyze the strategies competitors can employ to achieve profit-maximizing equilibria in a market characterized by fluctuating demand. Their study presents a model that examines the competitive behavior of multiple suppliers in a market where a single product is being sold. The concept behind SFE is to represent individual provider behavior by establishing a supply function that connects the quantity of an item or service that a supplier is willing to offer to the market price. The Nash equilibrium, which is the point where no player can improve their payoff by changing their strategy, does not require the demand for the product to be elastic. The SFE model represents suppliers' behavior using supply functions, rather than price-quantity pairs, creating elasticity in the residual demand faced by each supplier. This means that even if the demand for the product is not responsive to price changes, the SFE model can still result in a sensible equilibrium outcome (Rudkevich, 2005)

Suppliers in the SFE model are supposed to have some uncertainty about the demand for their product, so they must make strategic decisions about how much to produce and at what price to offer it in the marketplace. To account for this uncertainty, the supply function is given as a function of market pricing and a random variable representing the supplier's private demand knowledge (Rudkevich, 2005)

Green and Newbery eventually adopted the SFE approach as a model for strategic bidding in a competitive spot market for energy. The SFE model is used in this context to evaluate the behavior of electricity generators who must make strategic decisions about how much electricity to produce and at what price to sell it in a spot market where the price is decided by the intersection of supply and demand. Because it allows for strategic interactions between suppliers and captures the uncertainty that they face, the SFE model is a useful tool for analyzing supplier behavior in a competitive marketplace. The SFE approach provides a way to model the behavior of individual providers and study the equilibrium outcomes that follow from their strategic interactions by describing supply functions that depend on market pricing and a random variable representing private information (Rudkevich, 2005)

The utilization of the Supply Function Equilibrium (SFE) concept in modeling strategic behavior in energy markets has emerged because of the deregulation of the electric industry in several countries over the past decade. Analysts and consultants have developed tools that enable them to directly observe market power, estimate the influence of strategic actions on electricity pricing, and evaluate the market value of power generation assets (Rudkevich, 2005).

Electricity generators can use the SFE model to calculate the ideal amount of electricity to produce and the price at which to sell it in the market to maximize profits while also taking into account the behavior of their competitors. The SFE model has become a significant tool in the research and regulation of electricity markets, assisting in the preservation of competition and the provision of fair rates to customers. Green and Newbery enhanced the supply function equilibrium (SFE) theory by integrating capacity limitations and contracts for differences in the SFE framework (Rudkevich, 2005)

By evaluating the profit margins of market enterprises, the Supply Function Equilibrium (SFE) model can be utilized to calculate market power. Firms in the SFE model select their supply functions in order to maximize their total profit throughout a game period. Following the selection of supply functions, the Market Administrator (MA) responds with price limits and an Inter-Participant Dispatch Factor (IPDF). Pj = Pj(qj,T,p0,p1) denotes the profit margins of each firm, where qj is the supply function of firm j, T is the IPDF, and p0 and p1 are the price restrictions set by the MA. It is feasible to evaluate whether any corporations have market power in the electrical industry by evaluating these profit margins.

3.2.3.1 Constraints of Supply Function Equilibrium for Market Power Detection

The SFE model implies that each supplier has perfect information about its competitors' supply functions, which means that it knows exactly how much its competitors are willing to supply at each price level. In practice, however, this assumption may not be correct. Due to reasons such as inadequate or asymmetric information, high transaction costs, or other impediments, firms may not have access to their competitors' supply function information, or they may be unable to effectively estimate their competitors' supply functions. In the liberalized energy market, a lack of complete information can lead to false market predictions and make detecting market power difficult. For example, if a supplier overestimates the willingness of its competitors to sell power at a specific price level, it may charge a greater price than it would in a fully competitive market. In contrast, if a supplier underestimates its competitors' willingness to supply electricity at a certain price level, it may underprice its electricity and forego potential profits. Furthermore, firms may engage in strategic behavior to conceal their true supply functions, such as submitting false bids or withholding supply. Such deliberate activity can aggravate the problem of incomplete information, making it difficult to identify genuine market results and market dominance.

Inaccurate market projections can lead to market inefficiencies, which can result in higher electricity prices, lower consumer welfare, and lower social welfare. Policymakers and regulators can implement measures to boost transparency and promote the flow of information between suppliers to limit the impact of incomplete information. Such solutions could include mandating suppliers to declare their supply functions or establishing a centralized market operator to collect and disseminate supply and demand information. While the SFE model provides a valuable framework for assessing competition in the liberalized energy market, the assumption of perfect information may not always hold true in practice, and detecting market power in the presence of imperfect information might be difficult. Policymakers and regulators should be aware of the SFE model's limitations and take actions to mitigate the impact of incomplete market information.

The SFE model implies that enterprises maximize their profits and compete independently without collaborating with one another. Each firm presents a supply function indicating how much electricity it is willing to supply at given costs. The intersection of all the supply functions given by the suppliers determines the market price. However, firms may engage in strategic behavior in order to increase their profits. This could involve price-fixing, which occurs when firms agree to charge the same price or limit output in order to raise the market price of electricity. By limiting competition and raising prices, such purposeful behavior can distort market outcomes and lower consumer welfare. Collusion among enterprises can also make detecting market power in the liberalized electricity market challenging. When firms band together, they can behave as monopolies and demand higher prices without concern of losing clients to competition. A high concentration index combined with inelastic demand indicates that firms will use their market dominance to set prices much above costs (Ciarreta & Espinosa, 2003).

Firms may engage in subtle kinds of collusion that are difficult to identify, making detecting collusive behavior difficult. For example, firms may use coordinated bidding strategies or exchange information about their supply functions to coordinate their behavior.

While the SFE model provides a valuable framework for assessing competition in the liberalized energy market, it presupposes that firms maximize profits and do not collude. In fact, corporations may engage in strategic behavior such as price fixing or output constraints to boost profits, which can skew market outcomes and make detecting market power difficult. Policymakers and regulators must be aware of these challenges and take steps to foster competition and discourage market collusion. To solve these challenges, regulators and policymakers may need to put in place tools to prohibit and detect market collusion. They may, for example, enforce antitrust laws to prevent corporations from engaging in anticompetitive behavior, or they may require suppliers to publish information about their supply functions to boost transparency and foster competition.

The SFE model is a valuable tool for assessing competition in power markets in the short run. However, it may not be appropriate for studying long-term market behavior or investment decisions. One shortcoming of the SFE model is that it does not account for the implications of new market entrants. In a competitive market, new enterprises may enter, affecting the supply and demand balance. This might result in price shifts and market results. The SFE model, on the other hand, assumes a set number of suppliers and that the supply functions given by each firm remain constant.

Another shortcoming of the SFE model is that it does not account for technological advances that may impact supply and demand over time. The cost of producing electricity may decrease as technology progresses, causing changes in supply and demand dynamics. For example, increased usage of renewable energy sources like wind and solar power may lessen reliance on traditional fossil fuels, causing changes in supply and demand balance. Furthermore, the SFE model assumes that the market is stable and that demand and supply remain constant. In reality, electricity consumption may fluctuate due to a variety of reasons such as weather conditions or changes in consumer behavior. Because of these limitations, the SFE model should be used in tandem with other methods and approaches to acquire a more thorough knowledge of market dynamics and hence accurate information on the exercise of market power.

3.2.4 Agent Based Model (ABM)

ABMs are computational models that simulate how agents interact in a shared environment, assessing their performance and behavior. By capturing the intricate behavior of participants in electricity markets, including factors like asymmetric information and diverse strategies, they are able to model intricate issues in these markets. Furthermore, in extensive systems featuring diverse participants engaged in different roles and interacting with one another, agent-based modeling is better suited as it can faithfully replicate the behavior exhibited by real-world market participants. The underlying concept of agent-based modeling (ABM) is that agents make strategic choices based on their past interactions with other agents and their environment. Since agents often possess limited and imperfect information, they adapt their strategies by leveraging their prior experiences to enhance their decision-making abilities. (Shinde & Amelin, 2019)

ABM comprises three main concepts:

- Agents: These are computer codes that operate independently in a given environment, and have traits like autonomy, reactivity, social ability, and proactivity. In the electricity market, agents may include generators, system operators, customers, regulator, and retailers. (Shinde & Amelin, 2019)
- Artifacts: These are the system's passive components that are created, shared, modified, and used by the agents to perform their activities in a cooperative or competitive manner. Transmission lines in the electricity market are an example of an artifact. (Shinde & Amelin, 2019)
- Workspaces: These are the environments where the agents and artifacts interact, shaping the topology of the system and the idea of locality. (Shinde & Amelin, 2019)

Table 3: Electricity Market Agents (Macal et al., 2015)

Agents	Attribute	Objectives
Generating Company Agent (GenCo)	GenCo Identifier Power plant owner	Maximize net revenue
Independent System Agent Operator (ISO)	Iso Identifier Gencos bidding power into day ahead energy and ancillary services market	Balance demand and supply and maximize net social welfare
Demand Company Agent (DemCo)	DemCo indentifier Associated customer agents Obtain demand load from customer	Maximize net revenues
Customer Agent (Cust)	Cust Identifier Nominal load consumption profile	meet the power requirements for end-use services while minimizing costs
Transmission Company Agent (TransCo)	TransCo identifier Transmission assets owned	Supply power over transmission grid to meet distribution requirement

The experiment shown in figure 1, 2 & 3 below aims to examine potential future electricity markets by considering different assumptions regarding agent behaviors, with a specific focus on the bidding strategies of generating companies (GenCos). The experiments were carried out on a simulation model of the Illinois power grid, which encompassed 2,522 transmission lines, 1,908 buses, 66 power plants, 20 generating companies (GenCos), 852 load buses, 18 load zones, and 113 geospatial objects. The agents devised strategies in the space of price, quantity, and time, and refined their strategies based on the selection of their bids in the day-ahead market and the profitability they achieved. These experiments spanned a duration of 8,760 hours. Results are shown for two generation companies, GenCo1 and GenCo2, where GenCo1 can exert market power and GenCo2 is unable to (Macal et al., 2015).

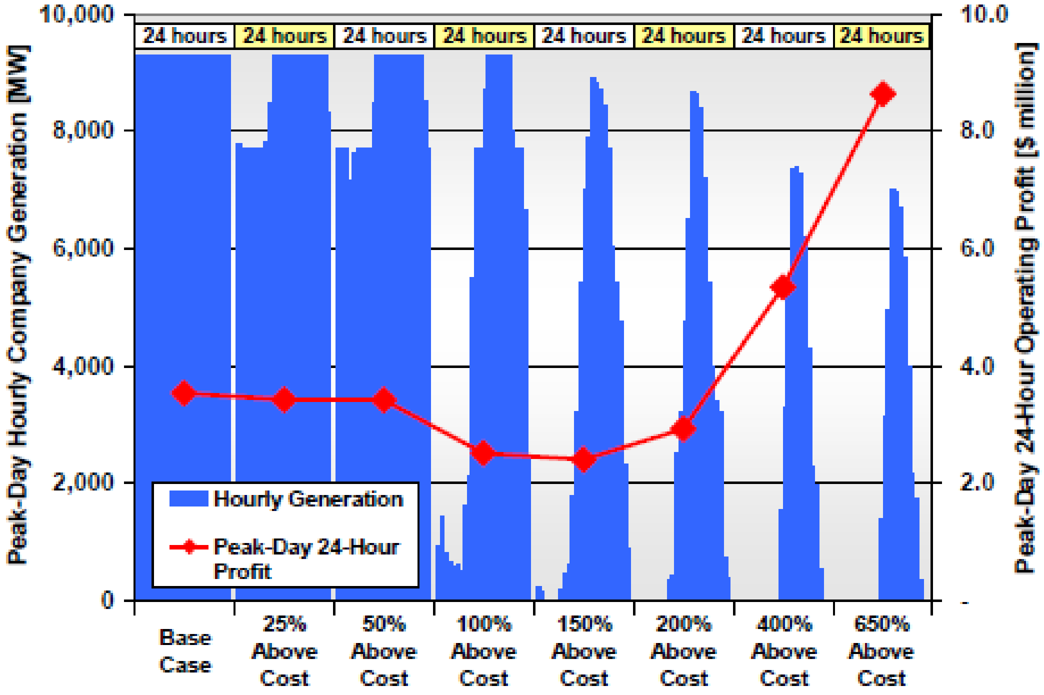

Figure 1: GenCo 1 24 hrs strategic bidding. (Macal et al.,2015)

Figure 1 illustrates the strategic bidding process of GenCo1, which successfully exercised market power. The figure demonstrates the impact of pricing all units in GenCo1's portfolio above their production cost, specifically on the peak day of the year. The graph depicts the relationship between GenCo1's bid prices and its generation levels over a 24-hour period. When all generating companies (GenCos) price their units at their production costs, GenCo1's generation remains constant throughout the day. However, as GenCo1 raises its bid prices above production costs, its portfolio generation declines, and the company's operating profits initially decrease. The decline in profits is observed when GenCo1 sets bid prices that are up to 150% higher than the production cost. This outcome is due to the availability of less expensive generation options from both study-area and out-of-area sources, along with sufficient transmission capacity to meet the load requirements (Macal et al., 2015).

Nevertheless, as bid prices continue to rise (reaching 200% above production cost), the operating profits of GenCo1 experience rapid growth. This occurs because a portion of GenCo1's capacity becomes necessary to fulfill the load requirements, while transmission constraints restrict the utilization of less expensive capacity from other sources. As a result, GenCo1 benefits from increased profits in this scenario. However, as the bid price rises, the profits of GenCo1 are constrained by the substitution of other producers. Nonetheless, the substitution is restricted due to grid limitations that restrict power transfer, thereby enabling GenCo1's profits to rise (Macal et al., 2015)

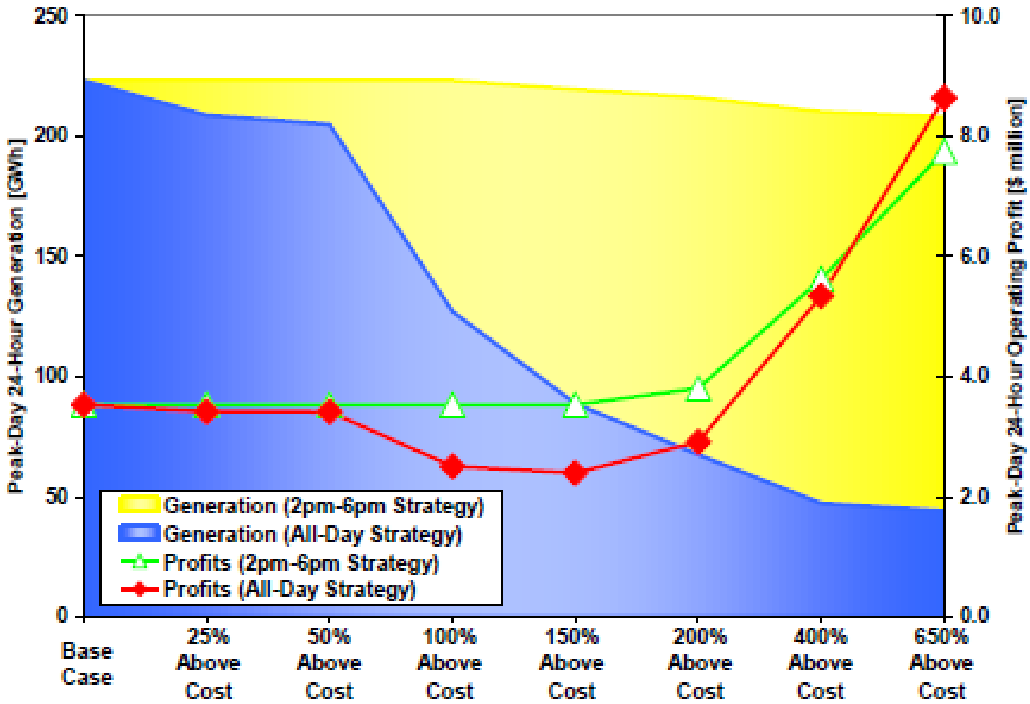

Figure 2: GenCo1 profit for various bidding strategies. (Macal et al.,2015)

Figure 2 presents a comparison of GenCo1's profits between two pricing strategies. The first strategy involves raising bid prices for all 24 hours, while the second strategy focuses on increasing bid prices solely during the afternoon hours from 2:00 pm to 6:00 pm, which corresponds to the peak period (Macal et al.,2015)

The graph illustrates that if GenCo1 were to implement its pricing strategy throughout the entire day, daily generation would experience a substantial decrease. However, if the company were to exercise its market power solely during the peak period in the afternoon, generation would remain relatively stable despite significant price increases. This indicates that the latter strategy is more favourable for GenCo1, especially if the company aims to minimize excessive cycling of its units. This is due to the fact that under this strategy, generation exhibits minimal fluctuation throughout the day, despite the notable price increases during the afternoon period.

Overall, figure 2 suggests that the pricing strategy employed by GenCo1 can have a significant impact on both its generation and operating profits. By adopting a strategy that focuses on the afternoon hours when the load is greatest, the company can maintain stable generation levels while still exerting its market power and increasing prices.

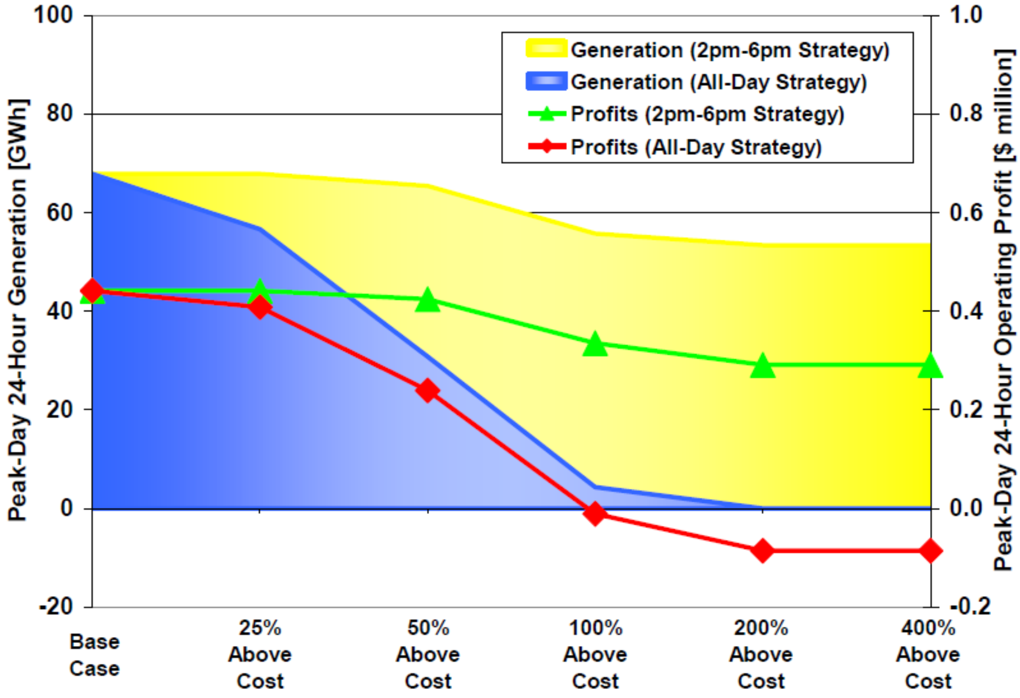

Figure 3: Genco 2 profits for various bidding strategies (Macal et al.,2015)

Figure 3 demonstrates that GenCo2 is unable to exert market power. In the graph, as GenCo2 increases its bid price for its portfolio of units throughout the day (24 hours), this leads to a rapid decline in its generations and replacements of all its generation units with cheaper units. This results in negative operating profits for GenCo2 as it continues to incur fixed operating expenses (Macal et al., 2015).

Even if the company applies this strategy during peak hours, it faces reduced profitability due to some of its units dropping out of dispatch and the inadequate compensation for the lower production. Therefore, the graph indicates that if a company cannot exert market power, indiscriminately increasing bid prices for the entire day or even during peak hours could lead to a decline in generation and negative operating profits.

The experiments show the impact on generation, operating profits, and bid prices for both GenCos when prices are increased above production costs. The experiments reveal that as bid prices continue to increase, operating profits grow rapidly until grid restrictions that limit power transfer and increased profits for GenCo1 eventually result. The analysis conducted has revealed that certain companies may have the ability to exercise market power, which involves unilaterally raising prices, and this can result in increased costs for consumers under certain conditions, especially in the presence of transmission congestion. This suggests that these companies may have the ability to manipulate the market by taking advantage of conditions that limit the supply of electricity or increase demand, which allows them to charge higher prices without facing competition from other companies. The findings of this analysis highlight the need for policies and regulations to prevent market manipulation and ensure fair competition in the energy market.

3.2.4.1 Constraints of Agent Based Model for Market Power Detection.

Agents in agent-based modeling (ABM) are often believed to obey rules or behaviors that are supposed to simplify their real-world behavior. These norms and behaviors are frequently based on assumptions and simplifications that may not adequately reflect the market's complexity and dynamism.

In an ABM of a liberalized power market, for example, generators are believed to constantly strive to maximize their profits by bidding at a specific price, while consumers are considered to always try to minimize their electrical expenses by selecting the lowest-priced supplier. In practice, generators may have aims other than profit maximization, such as system dependability or market share retention. Furthermore, consumers may be influenced by variables other than price, such as the reputation of the supplier or the environmental impact of the electricity generation. These assumptions and simplifications can be problematic if they do not accurately capture the real-world behavior of agents in the market. If the behavior of agents in the model does not match the real-world behavior, the model may generate inaccurate or unrealistic results. For example, if generators are assumed to always bid at a certain price, the model may not capture the strategic behavior of generators who may strategically manipulate their bids to increase their market power.

Furthermore, the assumptions and simplifications in ABMs can be based on incomplete or imperfect information. In reality, market participants may have incomplete or imperfect information about market conditions and the behavior of other participants, which can influence their behavior. ABMs may not accurately capture this uncertainty, which can lead to inaccurate results. While assumptions and simplifications are necessary in ABMs to simplify the complex behavior of agents in the market, it is important to carefully consider the validity of these assumptions and ensure that they accurately capture the real-world behavior of market participants. Failure to do so can result in inaccurate or unrealistic results, which can have negative consequences for policy-making or decision-making in the liberalized electricity market.

Another limitation is the Computational complexity which refers to the amount of computational resources required to run an agent-based model (ABM). ABMs are often computationally intensive, especially when dealing with large-scale systems that involve a large number of agents. This can limit their scalability and practical applicability.

The computational complexity of an ABM is affected by several factors, including the number of agents, the complexity of their behavior, the level of detail in the model, and the time horizon of the simulation. For example, simulating a market with thousands of generators, retailers, and consumers requires significant computational resources, as each agent must be modeled and simulated in the model. Additionally, the complexity of the behavior of agents can also increase the computational complexity of the model. This can include factors such as strategic behavior, learning, and decision-making.

The computational complexity of ABMs can limit their scalability and practical applicability. For example, if the computational resources required to run the model are too high, the analysis may become impractical or even impossible. Additionally, the time required to run the model can limit its usefulness in real-time decision-making applications, where decisions must be made quickly based on current market conditions.

Lack of transparency is another key limitation of agent-based models (ABMs). ABMs can be opaque and difficult to interpret, which can make it challenging to identify the underlying causes of market outcomes and to validate the accuracy of the model. This lack of transparency can have important implications for decision-making and policy-making in the liberalized electricity market.

One of the main challenges with ABMs is understanding how the model generates certain emergent behaviors. Emergent behaviors are those that arise from the interaction of agents in the model, rather than being explicitly programmed into the model. Emergent behaviors can be difficult to predict and understand, and it can be challenging to trace the effects of individual agent behaviors on market outcomes. As a result, it can be difficult to interpret the results of the model and understand the underlying causes of market outcomes.

Another challenge with ABMs is validating the accuracy of the model against real-world data. ABMs can be highly complex, with many interacting variables that are difficult to isolate and control. This can make it challenging to validate the model against real-world data, as it can be difficult to identify which variables are driving market outcomes and to isolate the effects of individual agent behaviors on market outcomes.

The lack of transparency in ABMs can be addressed through a variety of techniques. One approach is to use visualization tools to help understand the behavior of the model and the underlying causes of market outcomes. Visualization tools can help to identify patterns in the behavior of agents and to trace the effects of individual agent behaviors on market outcomes. Another approach is to use sensitivity analysis to identify the key drivers of market outcomes and to test the robustness of the model against different scenarios.

Lack of transparency is a key limitation of agent-based models in the liberalized electricity market. Understanding the underlying causes of market outcomes and validating the accuracy of the model against real-world data is essential for decision-making and policymaking in the market. While lack of transparency can be challenging, visualization tools and sensitivity analysis can help to address this limitation and improve the interpretability of the model.

3.2.5 The New Empirical Industrial Organization (NEIO)

The New Empirical Industrial Organization (NEIO) is an economic framework used to analyze and understand market behavior, particularly in industries with imperfect competition. NEIO has been applied to various sectors, including the liberalized electricity market, to measure the competitiveness of market. Unlike the other previous models studied which directly measures market power, NEIO seeks to measure the competitiveness of the market and the possibility of market power. (Pham, 2019)

The NEIO (New Empirical Industrial Organization) approach entails developing and estimating structural econometric models to examine firms' strategic behavior in competitive markets.

Firms' decisions in these models are based on some type of optimizing behavior, often profit maximization. This method varies from structural consumer choice models, which assume non-strategic behavior. Consumer choice models presume that one consumer's choice has no effect on another consumer's choice, allowing for modeling independence. In NEIO models, however, firm choices are interconnected, which means that a firm's decision will evoke a response from its competitors. This strategic behavior modeling distinguishes structural models of consumer choice from structural models of firm choice (Kadiyali et al., 2001).

This distinction between consumer and firm choices has two econometric implications. First, there is the issue of simultaneity. In strategic firm models, firms make their marketing mix choices simultaneously, where each firm's choice depends on its rivals' choices, and vice versa. Additionally, firm choices affect market demand, and demand characteristics, in turn, influence firm choices. To account for simultaneity, the demand equations and choice equations of firms are estimated as a system of simultaneous equations (Kadiyali et al., 2001).

The second issue is endogeneity. In consumer choice models, individual choices are assumed to have no effect on firm decisions such as prices and promotions. Consequently, firm decisions are treated as exogenous. However, in structural models of firm choice, where separate equations for firm choices are estimated, these choices are considered endogenous. To address endogeneity, instruments are used for the choice variables to account for their interdependence. In summary, the NEIO approach involves developing structural econometric models to analyze strategic behaviour in firms. These models account for the interdependency of firm choices, addressing issues of simultaneity and endogeneity. By estimating these models, researchers gain insights into the strategic behaviour and decision – making processes of firms in competitive markets. (Kadiyali et al., 2001).

(Pham, 2019) described the NEIO Model using two(2) approaches. Firstly by estimating the firms behaviour or the average behaviour of all firms in an industry, as well as estimating marginal cost, using a structural model. This approach requires estimating three sets of unknown parameters: cost, demand, and the firm's behavior. In this approach, the observable variables are those that are determined within the market equilibrium. These variables in the context of the model include price and system turnover. Price denotes the cost of the firm's product or service, whereas system turnover denotes the total output or sales of the firm or the industry as a whole.

Exogenous variables, on the other hand, are factors that are external to the model and influence the cost and demand functions. These variables are not determined by the model but are considered to understand their impact on costs and demand. Changes in input prices, regulatory policies, technological advancements, or consumer preferences are examples of exogenous variables.

The second approach discussed by (Pham, 2019), is to conduct a reduced form analysis to analyze how prices respond to changes in costs or cost influencing factors. This method investigates if variables that affect costs for all other enterprises rather than the firm’s own quantity, may experience price change. If the empirical research shows that changes in these cost shifting variables have a stronger link with prices than changes in the firm’s own quantity, the firm does not possess market power.

One advantage of this approach is that it requires less data and makes fewer assumptions compared to structural models. Instead of estimating complex structural relationships and unknown parameters, the focus is on observing price responses to cost changes. By examining how prices vary in relation to shifts in costs, researchers can infer whether the market operates under competitive conditions. However, it's important to note that this approach is primarily used to assess market competitiveness rather than providing a direct estimate of market power. While it can provide insights into the presence or absence of market power, it does not quantify the exact extent or level of market power held by a firm. For a more detailed analysis of market power, structural models and estimation of unknown parameters are typically employed.

3.2.5.1 Constraints of NEIO Model for Market Power Detection.

NEIO models face the challenge of endogeneity, particularly in the analysis of firm behavior. The interdependence of firms' choices and market outcomes creates a simultaneous relationship, where firms' decisions are influenced by market conditions, while at the same time, their actions impact market outcomes. Endogeneity can introduce bias and complicate the identification of causal relationships. (Kadiyali et al., 2001). Endogeneity refers to a situation in which two or more variables are jointly determined, meaning they are interdependent and influence each other. In the context of NEIO models and the analysis of firm behavior, endogeneity poses a significant challenge.

In NEIO models, firms' choices, such as pricing strategies or production levels, are influenced by market conditions, including factors like competitors' actions, demand fluctuations, and cost structures. At the same time, the decisions made by firms have an impact on market outcomes, such as prices, quantities, and overall market equilibrium. This simultaneous relationship between firms' choices and market outcomes creates endogeneity.

The presence of endogeneity can introduce bias and complicate the identification of causal relationships. It becomes challenging to determine whether a change in a firm's behavior leads to a particular outcome or if the outcome influences the firm's behavior. In other words, distinguishing between cause and effect becomes difficult.

For example, consider a situation where two competing firms in the electricity market simultaneously adjust their prices. If a NEIO model does not account for endogeneity, it may incorrectly attribute the change in prices to one firm's behavior when, in reality, the change in prices is a result of both firms reacting to each other's actions. Endogeneity can lead to biased and inconsistent parameter estimates, as well as misleading conclusions about the presence or extent of market power. It can undermine the accuracy of market power assessments and the effectiveness of policy recommendations.

To address endogeneity, econometric techniques such as instrumental variable estimation, simultaneous equations modeling, or dynamic panel data methods are often employed. These techniques aim to identify exogenous variables that can serve as instruments, allowing for the identification of causal relationships and mitigating the bias introduced by endogeneity.

By appropriately addressing endogeneity, NEIO models can provide more reliable insights into firm behavior, market outcomes, and the presence of market power. However, careful consideration and robust econometric methods are necessary to handle the complexities introduced by endogeneity and obtain accurate estimations of causal relationships in the analysis of firm behavior within the NEIO framework.

Another challenge faced by the NEIO Model is assumption. When estimating market power using the New Empirical Industrial Organization (NEIO) approach, the results are highly dependent on two key factors: the assumed type of strategic interaction among firms and the assumed functional form of demand and cost curves. (Pham, 2019)

Assumed Type of Strategic Interaction: NEIO models aim to capture the strategic behavior of firms in an industry. The assumed type of strategic interaction refers to the specific way in which firms interact and compete with each other. Different strategic interaction assumptions can lead to varying estimates of market power. For example, researchers may assume a Bertrand competition model, where firms compete by setting prices, or a Cournot competition model, where firms compete by choosing quantities. Each model represents a different type of strategic interaction and can result in different market power estimates. The choice of the strategic interaction assumption depends on the characteristics of the industry under study and the available data.

Additionally, assumptions about collusion or the presence of dominant firms can also influence market power estimates. If firms are assumed to collude and act as a single entity, the estimated market power may be higher compared to a competitive scenario where firms act independently.

Assumed Functional Form of Demand and Cost Curves: NEIO models require specifying the functional form of demand and cost curves to estimate market power. The functional form determines the relationship between various factors, such as price, quantity, cost, and market demand. The choice of functional form can have a significant impact on market power estimates. Different functional forms can lead to different shapes of demand and cost curves, resulting in varying estimates of market power. For example, assuming linear demand and cost curves may yield different results compared to assuming non-linear curves.

The functional form of demand and cost curves can be influenced by factors such as market structure, consumer behavior, production technology, and the nature of competition in the industry. The researcher's prior knowledge and understanding of the industry dynamics play a crucial role in determining the appropriate functional form.

It is worth noting that selecting an incorrect functional form can lead to biased or inconsistent estimates of market power. Therefore, researchers must carefully evaluate the available data and consider economic theory and empirical evidence when choosing the functional form. To mitigate the impact of assumptions and functional form choices, sensitivity analyses can be performed. Researchers can test different types of strategic interaction assumptions and alternative functional forms to assess the robustness of their findings. NEIO estimates of market power depend crucially on the assumed type of strategic interaction among firms and the assumed functional form of demand and cost curves. Careful consideration of these factors is necessary to ensure accurate estimation and interpretation of market power in empirical analyses.

The application of New Empirical Industrial Organization (NEIO) models in the electricity market may have limitations compared to multi-agent models. NEIO models rely on observable data outcomes such as prices, volumes, and associated data to analyze market power. While these models can measure the level of market power, they may not provide as much flexibility to integrate assumptions and consider various players.

Unlike multi-agent models, NEIO models may not be as effective in investigating the underlying factors that drive changes in market power. They focus on analyzing the observed outcomes rather than exploring the endogenous and exogenous factors that may influence the level of market power. As a result, NEIO models may not provide a comprehensive understanding of the causes behind the increase or decrease in market power.

In summary, NEIO models can be useful for measuring the level of market power in the electricity market based on observable data. However, they may not offer the same degree of flexibility and insight into the underlying factors influencing market power as multi-agent models.

4. Discussion

The current energy market faces a dilemma with players leveraging market power, exploiting loopholes, and cooperating to maximize profit. This comes at a cost to consumers who rely on electricity, as it is an inelastic product with constant demand regardless of price fluctuations. The traits of electricity enable the abuse of market power. To provide a solution, it's crucial to identify if the problem exists in a specific case, as there are various factors that can cause price spikes in the electricity market, not necessarily related to market power abuse. Hence, detecting the utilization of market power is essential. Two main approaches are discussed: the structural approach and the market simulation approach. The structural approach which links the lack of competition in the market to the amount of market shares owned by players in the market, in order words, it focuses on potentials of market players to exercise market power. Whereas, the second approach which is the market simulation focuses on how much market power has already been exercised and who is responsible for it.

The structural approach examines the competitiveness of the energy market by analyzing market shares of the largest firms using metrics like the Concentration Ratio (CRn) and the Herfindahl-Hirschman Index (HHI). However, these metrics do not consider market segmentation, interdependencies, or dynamic market conditions, making them unreliable for market power detection.

On the other hand, the Pivotal Supplier Indicator (PSI) and Residual Supply Index (RSI) take into account the demand side of the electricity market. PSI determines if a supplier can exert market power based on specific conditions, such as a PSI of 1 for over 20% of the hour or if RSI is less than 100% for more than 5% of the total hours in a year. PSI and RSI gives an indication of the dependency of market player to meet a significant share of the market demand and hence an indication of the potential of the market player exercising market power. While PSI and RSI are effective methods, they require detailed data on demand, supply, and capacity, which may be restricted or limited, affecting their accuracy and reliability. Additionally, they do not consider transmission constraints.

The Structure Conduct Performance (SCP) model focuses on how changes in market structure affect firm conduct and performance. However, it heavily relies on concentration ratios, which have limitations for detecting market power. Accurate data on market structure, firm behavior, and performance is crucial but may not represent the current market condition or project future scenarios accurately. The SCP model's measure of firm performance (cost price margin) does not align with the assessment of market power, which requires suppliers to bid at marginal cost. Overall, the SCP model is not accurate or efficient for market power detection.

The residual demand analysis, similar to PSI, examines the demand side of the electricity market but in a more complex manner. It considers the supplier's residual demand curve to assess their potential for market power. Like other structural approaches, data availability and transmission restrictions pose challenges to accurate results. Whilst residual demand analysis is good method for market power detection, it may produce inaccurate results if the stated challenges are not accounted for.

Market simulation approaches that focus on quantifying the extent of exerted market power offer a reliable means of detection. The linear optimization model compares marginal cost and hourly prices, flagging significant discrepancies as potential indications of market power abuse. However, this model faces obstacles like uncertainties and inaccuracies in transmission networks and the failure to account for power plant ramping limitations. Combining this method with the residual demand analysis model would enhance efficiency.

The Cournet-Nash model utilizes inverse demand curves as a primary tool for market power detection. However, this approach relies on assumptions that may not reflect the true extent of market power and is hindered by limited historical data for emerging markets. Additionally, the dynamic nature of the electricity market and lack of transparency pose further challenges, potentially leading to erroneous indications of market power.

Supply function equilibrium, which evaluates profit margins between firms' actual and optimal levels, also has limitations. Assumptions such as suppliers having access to competitors' supply functions and firms solely maximizing profit without collusion can impact result accuracy. Furthermore, it fails to account for new market entrants and technological advancements that significantly influence supply and demand over time. Combining supply function equilibrium with other methods is crucial for obtaining accurate market power detection outcomes.

Agent-based models, where agents make strategic choices based on past experiences, can be employed alongside other methods for market power detection. However, these models have limitations such as assumptions and simplifications that, if incorrect or not aligned with real-world behaviors, can yield erroneous results. Transparency and computational complexity also pose challenges. Nevertheless, when used appropriately, agent-based models serve as valuable tools for market power detection, especially when complemented by methods like concentration ratios.

In summary, market simulation approaches quantifying exerted market power, linear optimization, Cournet-Nash, and supply function equilibrium have their limitations, combining them with other methods enhances accuracy. Agent-based models, while subject to certain challenges, prove useful when appropriately utilized alongside other market power detection techniques like concentration ratios.

NEIO analyzes market behavior and measure competitiveness, unlike previous models that directly measure market power, NEIO focuses on measuring market competitiveness and the possibility of market power. NEIO models consider firms' strategic behavior and interdependent choices, distinguishing them from consumer choice models that assume non-strategic behavior. These models address the challenges of simultaneity and endogeneity. Market power in NEIO models which is estimated by analyzing firms' behavior or conducting reduced form analysis of price responses to cost changes. However, the accuracy of market power estimates in NEIO models relies on assumptions regarding the type of strategic interaction among firms and the functional form of demand and cost curves. Endogeneity, arising from the interdependency of firm choices and market outcomes, poses a significant challenge in NEIO models and requires careful econometric handling. Furthermore, NEIO models may not provide the same flexibility and insight into the underlying factors driving changes in market power compared to multi-agent models. They primarily focus on observable data outcomes and may not comprehensively explore the causes behind changes in market power.

5. Conclusion

In conclusion, the current energy market faces challenges related to market power abuse, which negatively impacts consumers who rely on electricity. Detecting and addressing market power is crucial for ensuring fair competition and protecting consumer’s interest. Two main approaches, the structural approach and the market simulation approach, are discussed in this MSc thesis.

The structural approach, which analyzes market shares and concentration metrics, provides insights into the competitiveness of the energy market. However, it has limitations in considering market segmentation, interdependencies, and dynamic market conditions, making it less reliable for market power detection. Metrics like the Pivotal Supplier Indicator (PSI) and Residual Supply Index (RSI) take into account the demand side of the market, but they require detailed data and may not consider transmission constraints. The Structure Conduct Performance (SCP) model examines how changes in market structure affect firm behavior and performance, but it heavily relies on concentration ratios, which have limitations in detecting market power. The residual demand analysis, similar to PSI, provides a more complex examination of the demand side but also faces challenges related to data availability and transmission restrictions.

Market simulation approaches offer a reliable means of detecting market power by quantifying its extent. The linear optimization model compares marginal costs and prices to identify potential abuses. Combining this approach with residual demand analysis can enhance detection efficiency. The Cournet-Nash model, based on inverse demand curves, is another method for market power detection but relies on assumptions and limited historical data. Supply function equilibrium analyzes profit margins between actual and optimal levels but has limitations related to assumptions and technological advancements. Agent-based models, although subject to challenges such as assumptions and computational complexity, prove useful when used alongside other methods. They provide insights into strategic choices made by market agents. NEIO models, focusing on market competitiveness and strategic behavior, address simultaneity and endogeneity challenges but may lack the flexibility to explore underlying factors driving changes in market power.

In summary, a combination of market simulation approaches, such as the linear optimization model, along with other methods like residual demand analysis, concentration ratios, and agent-based models, appears to offer a comprehensive approach to market power detection. The linear optimization model, by comparing marginal costs and prices, can identify potential discrepancies that may indicate market power abuse. Combining this approach with residual demand analysis provides a more nuanced understanding of the demand side of the market. Additionally, considering concentration ratios and utilizing agent-based models to capture strategic choices and behaviors of market participants can enhance the accuracy of market power detection. It is essential to overcome data limitations, consider transmission constraints, and account for dynamic market conditions when implementing these approaches. By effectively detecting market power, policymakers and regulators can take appropriate measures to foster competition and protect consumers in the energy market.

Economic Study

This is an economic analysis of MSc thesis work (February 1st, 2023 – June 30th, 2023)

Start date: February 1st, 2023

End date: July 1st, 2023

Table 4: Economic Value of MSc Thesis

Description	**Time spent (in hours)**	**Hourly rate (€)**	**Hours**	**Total amount**
MSc thesis Project	900	11€	900	9.900€
VAT		21%		2.079€
Sum total				**11.979€**

The total economic value for the project is 11.979€

Planning.

The project was planned for a period of 5 months and the figure 4 below shows work plan for each task in the MSc Thesis work

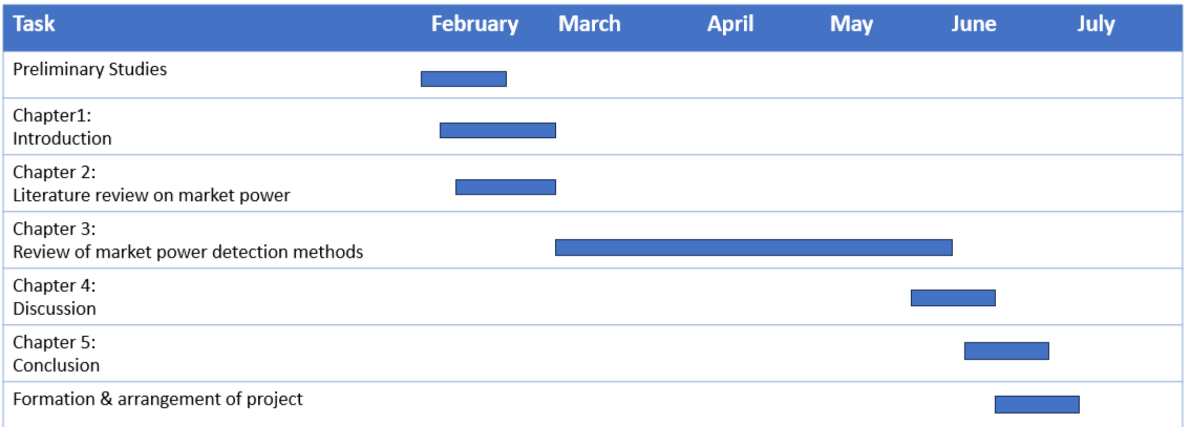

Figure 4: Work plan of MSc Thesis Project Work

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