WELFARE ANALYSIS
IN AN IMPERFECTLY COMPETITIVE ELECTRICITY MARKET
WITH DISTRIBUTED RENEWABLE GENERATION

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Welfare Analysis in an Imperfectly Competitive Electricity Market

With Distributed Renewable Generation

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DECLARATION OF ORIGINALITY

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ABSTRACT

Welfare Analysis in an Imperfectly Competitive Electricity Market
With Distributed Renewable Generation

This thesis aims to analyze the optimal amount of renewable electricity generation using the dominant firm and the fringe model. In this model, the dominant firm(s) produces non-renewable electricity and the fringe produces renewable electricity. The fringe represents the distributed renewable energy generation that has become a phenomenon in Turkey in the last decade. The optimality stems from the trade-off assumption that generating renewable energy is more costly and non-renewable energy causes environmental externalities. Solving the model under fixed and premium tariffs and for different number of oligopoly firms allows examining the differences between the two FiT mechanisms and the effects of market power and marginal costs on the equilibrium outcome. Matlab software is used to simulate the solutions over a set of chosen parameters to show these effects graphically. Shortly, in the concentrated markets, the fixed tariff outperforms the premium tariff in terms of total welfare, however, the premium tariff leads to higher renewable generation which can be preferred as well for environmental purposes. This effect is most evident in the monopoly and the fringe case. As the number of oligopoly firms increases, namely the market becomes less concentrated, the two policy mechanisms approximate each other. When the model is adjusted to the current HHI level of the Turkish electricity market, the two mechanisms generate nearly the same outcomes for the chosen set of parameters. Beyond these theoretical findings, this research proposes a framework to evaluate the optimality of the implemented tariff policies if the cost data is available.

ÖZET

Dağıtık Yenilenebilir Üretimli Eksik Rekabetçi Elektrik Piyasasında Refah Analizi

Bu tez, dominant firma ve kenar firmalar modelini kullanarak optimal miktarda yenilenebilir elektrik üretimini analiz etmeyi amaçlamaktadır. Bu modelde dominant firma(lar) yenilenemeyen elektrik üretir ve kenar yenilenebilir elektrik üretir. Kenar, Türkiye'de son on yılda fenomen haline gelen dağıtılmış yenilenebilir enerji üretimini temsil ediyor. Modeli sabit ve prim tarifeleri altında ve farklı sayıda oligopol şirketi için çözmek, iki sübvansiyon mekanizması arasındaki farkları ve piyasa gücü ile marjinal maliyetlerin denge sonucu üzerindeki etkilerini incelemeye olanak tanıyor. Matlab yazılımı, bu etkileri grafiksel olarak göstermek için seçilen bir dizi parametre üzerinden çözümleri simüle etmek için kullanıldı. Kısaca ifade etmek gerekirse, yoğunlaşmış piyasalarda sabit tarifenin toplam refah açısından prim tarifesinden daha iyi performans gösterdiği, ancak prim tarifesinin, çevresel amaçlar için de tercih edilebilecek daha yüksek yenilenebilir enerji üretimine yol açtığı sonucuna varılmıştır. Bu etki en çok tekel ve kenar firma örneğinde belirgindir. Oligopol şirketlerinin sayısı arttıkça, yani pazar daha az yoğun bir hale geldikçe, iki politika mekanizması etkileri itibariyle birbirine yaklaşıyor. Model, Türkiye elektrik piyasasının mevcut HHI seviyesine ayarlandığında, iki mekanizma seçilen parametre seti için hemen hemen aynı sonuçları üretiyor. Bu teorik bulguların ötesinde, bu araştırma, maliyet verilerinin mevcut olması halinde uygulanan tarife politikalarının optimalliğini değerlendirmek için bir çerçeve sunmaktadır.

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CHAPTER 1

INTRODUCTION

While the world is getting at the peak of the global warming crisis, clean energy technologies become more and more important every day from an environmental perspective. Moreover, from economic and political perspectives too, producing green energy instead of fossil-fueled production can be crucial even in the near future. Those perspectives provide some significant reasons for green energy investments such as maintaining energy security, fostering innovation, decreasing fuel dependence especially for resource lacking countries, and even increasing energy efficiency. All of those economic and political reasons, with some others not stated here, to some extent have validity, which is discussed in the energy economics literature, and their realizations mostly depend on the implementation of smart regulation policies. To design such policies, policy-makers needs to be informed about economic aspects of regulations, and namely, the outcome that is going to be reached by the responses of rational agents in the market, while not getting too far from the specific realities of policy scope.

Electricity is very close to representing the ideal concept of good theorized in economics because of its homogeneous feature. The same amount of electrical power, regardless of by whom it is produced or how it is produced, provides the same utility to consumers. Although it can be classified as green or brown concerning the externality such as the emission made during the production phase, this feature is till now not embodied in itself. Thus, it can be said that electricity is a homogeneous product from the perspective of the qualities of the electric power. Another important

feature of electricity is its non-durability. Storage and transmission of electricity are costly. Therefore, close to demand production can lead to efficiency gains.

There are different ways to plan the new energy structure and the change towards it for any country, either having more shares of monopoly or oligopoly of central producers, which can produce both green and brown energy or having greater shares of small scale distributed generation units, which generally use clean energy or low-carbon production technologies. The combinations among these options yield scenarios having different macro and micro aspects. Regarding the technology and location-specific characteristics; the advantages and disadvantages of the options should be weighted. In this study, I will try to evaluate the optimality and the efficiency of direct support mechanisms for renewable distributed generation, first from a theoretical perspective and then applying it to the case of Turkish electricity markets. The application will not consist of the empirical analysis of the market, but of some approximate comments regarding my theoretical conclusions. To do this, first I will briefly summarize the literature, explain how electricity markets work in Turkey, and construct the basic model and the extensions accordingly, then I will simulate the model on various settings that may represent Turkey's case, and present the results. Before moving to the academic literature, the story of the last thirty years of electricity markets around the world will be summarized without diving much into the country-specific technical features if they are not significant for the whole story.

Main direct support mechanisms for renewable energy generation are fixed and premium feed-in-tariffs. Under the premium tariff, the firms that are desired to be subsidised get a premium over the market price, while under the fixed tariff they get a tariff independent on the market price. Although variations and combinations of them are present in the application, taking these two main support ways as the basis of the

analysis can be insightful for pointing out the significant differences in the outcomes these policies generate. The reason behind choosing this topic as a research question is the fact that these policies have been implemented in Turkey for the last fifteen years, and the academic research is needed to propose a background for evaluating the success of the current or past policies. Although this study is not focusing directly on the policy evaluation, it has a target of contributing the current academic literature in terms of its application to find the optimal policies. Moreover, looking at the optimal tariff levels in terms of the sector parameters and the decision-maker's valuations of the environmental externalities, and the socialized costs of the support mechanisms have some significant implications about the support schemes, that will be analyzed for a set of parameters below.

Although several dimensions of electricity markets are discussed in the literature, the framework to find the optimal renewable distributed generation level is less studied relatively. The aim of this study is to compare two different promotion ways for the renewable energy generation, fixed tariff and premium tariff, and to propose a model to assess the efficient level of tariff given to the renewable energy sector, which is determined by the trade off between higher costs of renewable technologies compared to the conventional 'brown' technologies, and the environmental externality of these conventional technologies. Other than these two mechanisms, there are also more market-dependent measures such as green certificates, however, those measures are beyond the scope of this study because of two main reasons. First; they are not prevalent in the related scope of policy suggestion of this thesis, namely Turkey, and the second; those more market dependent measures are claimed to lead less efficient scenarios in terms renewable generation because of the market power issues.(der Fehr and Ropenus 2017)

To represent the distributed generation, a model of a fringe and a monopoly, or the Cournot duopoly and the fringe can be useful. Number of firms in the oligopoly can be increased as well to simulate the effects of increasing competition. Using the dominant firm and the fringe model is not new in the energy economics literature, the Cournot model has been used by (Cardell, Hitt, and Hogan 1997), (Borenstein and Bushnell 2003), and a monopoly and a fringe model by (Ropenus and Jensen 2009), and (der Fehr and Ropenus 2017).

CHAPTER 2

LITERATURE REVIEW

2.1 Restructuring the electricity markets

From its production to end-use, electric power has four stages: generation, transmission (including decreasing the voltage), distribution and retailing to end-users. Therefore, the four stages are subject to restructuring. Restructuring of electricity structure has occurred as privatization and deregulation of the existing structure, which was operated by either government-owned utilities or regulated natural monopolies prior to the deregulation. During the restructuring, new markets are generated to make electricity transactions possible. Those markets can be categorically classified into wholesale and retail markets in the first step. Wholesale trade of electricity may occur between generators as sellers and traders, responsible procurement firms, and large end-users like factories as buyers. Electric power is then sold to end-users in retail markets. Retail markets can also be restructured with either fix prices for small scale consumers and negotiated prices for large scale consumers, or with no regulated procurement firms at all. Restructuring the generation side means privatization of plants, deregulation of supply-side with the hope of competitive or contestable market outcomes. Restructuring of the transmission system is intended to prevent vertical integration of generators to deter entry by raising costs.

Since the ’90s, many countries have deregulated their electricity markets to have free-market conditions, such as competition, private initiatives, more efficient outcomes, etc. in the sector, after one of the first attempts was undertaken by the British government on April 1990. (Wolfram 1999) Some states in the United States followed the UK in the deregulation story, by adopting similar reforms. Prior to the

reforms between 1995-2002, customers were provided electricity by regulated monopolies who are subject to a cost-of-service type regulation. Those monopolies were responsible for all four stages of electricity provision. (Borenstein and Bushnell 2015) Successful deregulation stories in other sectors like telecommunication, airlines, railroad, etc. influenced governments to undertake a similar process in the electricity sector as well, by having more competitive conditions.

The deregulation process in the US focused on the restructuring of generation, transmission, and retail side while leaving the distribution to natural monopolies. Borenstein and Bushnell (2015) describe the deregulation of generation as moving from average cost pricing to marginal cost pricing, so some factors are making one of the two more advantageous. Unutilized reserve margins can increase the average costs under regulation, and factors that increase the marginal costs can increase competitive prices, like increasing fuel costs, if gas-fired power plants are inframarginal. They also argue that restructuring in one of the four stages is corresponding to each other. For instance, liberated retail markets would be affected by high wholesale prices if the supply-side is not competitive, or transmission providers can extracts rents of competitive generators. In summary, the authors conclude that although deregulation increased generation efficiency, whether the fall in prices was due to the restructuring is not clear. The main motivation behind it was rent-shifting, which is according to them, also the current motivation behind the change towards DG intensive systems.

2.2 How electricity markets work

To have independent and competing generators, traders and retail sellers operating securely, there should be market mechanisms for electricity trade in wholesale and retail scales. For the wholesale trade of electricity, various mechanisms are generated

in the UK, Europe, the US, and in some other countries followingly: a spot market for electricity trade (day-ahead and intraday markets) which is also called as a pool, bilateral agreements that are agreements on the master sets of general conditions after which the transactions occur at any size in any time, contracts that are ranging from difference payments for the spot price realizations above or below the contracted price, to forward contracts, financial contracts, etc.. At the retail scale of electricity resale to end-users, consumers are classified as free and non-free consumers, regarding their monthly consumption or peak consumption. While free consumers can choose their procurement agencies, non-free consumers buy electric power from regulated distributor companies that are responsible for the local area they invested in. Since the storage is costly and inefficient in large scales, demand and supply should match continuously. To ensure that, balance markets are also added to the system.

Although there are slight differences with regards to electricity markets, how they operate and the general structure are approximately the same in the modern electrical systems. The most complicated one of these mechanisms is the spot market or the pool of wholesale electricity trade. It is first designed as a uniform auction mechanism in the UK which later adopted the discriminatory auction mechanism in March 2001 to lower the prices. In discriminatory auctions, everyone pays their bids, however in uniform auctions, a day is split into periods, generally of half-hour, and the system marginal price is determined by an algorithm maximizing the total surplus. In other words, sellers and buyers state their supply and demand offers with size and price features and ranked in order. After which units will be dispatched is determined by the demand, “system marginal price” is determined for a given period, by the offer of a marginally operating unit. All operating units are paid the “SMP”.

2.3 Economics of distributed generation (DG)

Distributed generation is to produce electric power in the distribution lines rather than transmission lines, close to where it is consumed. Transmission lines are in which the high-voltage electricity is transmitted, from the generator plants to the substations close to the demand, while distribution lines transfer the low-voltage electricity from substations to the end-consumers. Distributed generation includes both renewables like solar photovoltaics, wind and micro-wind turbines, micro-hydro, and biomass/waste plants, and non-renewable low carbon production technologies increasing efficiency such as CHP (combined heat and power plants). Distributed generation can be of two types regarding the purpose of the generator: either only to meet the demand of residential or commercial consumers of electricity or also to sell the surplus generation to the grid. Therefore, the distributed generation requires an active network system that can take the electric power generated by the prosumer (producer and consumer at the same time) to the grid, so double way lines are required for the prosumer locations. However, it decreases the infrastructure spendings on the transmission network, which is subject to aging and capacity constraints. (Allan et al. 2015)

Optimum share of DG units in the energy portfolio of a country or a region depends on the technology and location-specific characteristics and also the pros and cons of DG systems. Supporting DG investments means encouraging green energy at the same time, although some DG systems are not renewables, they are at least low-carbon technologies. Even with non-renewable DG Technologies, such as cogeneration plants, it increases energy efficiency in commercial and residential buildings, factories, etc. Increasing the energy produced within a country or a state reduce energy and fuel dependency, and consequently leads to enhanced energy

security. As explained above, increasing the share of DG minimizes transmission costs of electricity which is a very important factor in electricity costs, also decreases the infrastructure spending on transmission lines. Encouraging DG investments also foster domestic innovation while making the technology cheaper in the medium run. It also can increase social awareness about electricity consumption and the way that it is produced.

On the other hand, DG has some disadvantages too, central production facilities have economies of scale advantages in the production process. DG units are generally not financially viable without subsidies. As explained, it also requires active networks so increases infrastructure spendings on the distribution network. The most important one of these disadvantages is that it has high installation costs at the beginning, which means a burden on tax-payers' shoulders.

Apart from the environmental and economic discussions regarding DG technologies efficiency, some views argue that there are political reasons like rent-shifting behind the motivation towards DG technologies. To give an example, in the current situation, with the encouragement over DG deployments, people get extra savings by not paying the transmission and distribution costs reflected in the bill, making it a larger burden on the other consumers' share. Even if they are made to pay those costs under a grid connection fee, if the storage technologies get efficient enough, they can completely leave the grid and get free from these charges. (Borenstein and Bushnell 2015)

2.4 Renewable energy statistics

In 2018, the share of renewables in total electricity production was 26 percent, with 36.4 percent in Europe, and up to 58.5 percent in Latin America. Though each

continent has varying shares, there is a general increase in RES shares worldwide, in power mix up to 0.8 points. That increase is mainly due to solar and wind installations, which was easier to finance relatively, because of falling costs. Share of renewable technologies even reaches to 97.9% in Norway and 82.3% in New Zealand, while it is around 32.4 percent in Turkey. (yearbook.enerdata.net) However, these numbers include hydropower generation as well. There has been a debate over whether the hydropower is renewable or not due to its possible environmental threats. However, it is a safer way not to include it since it has been one of the main components of electricity generation in many countries for decades, so counting it as a renewable generation at least leads to overestimated results.

In 2018, of total electricity consumption in Turkey, 37.3 percent was from coal, 29.8 from natural gas, 19.8 from hydroelectric plants, 6.6 from wind, 2.6 from solar energy, and 2.5 from geothermal energy. By the end of the first half of 2019, of total electricity produced, 7.2 percent was from wind and 3 percent was from solar energy. (enerji.gov.tr)

It can be seen from figure 1 that there is a general increase in renewable generation's share worldwide, while it is greater in Europe. The information is taken from BP's dataset, and their definition of renewables does not include hydropower generation. In 2018, Turkey's renewable share over its total electricity production is around 12,5 percent which is consistent with the consumption statistics revealed by the ministry of energy.

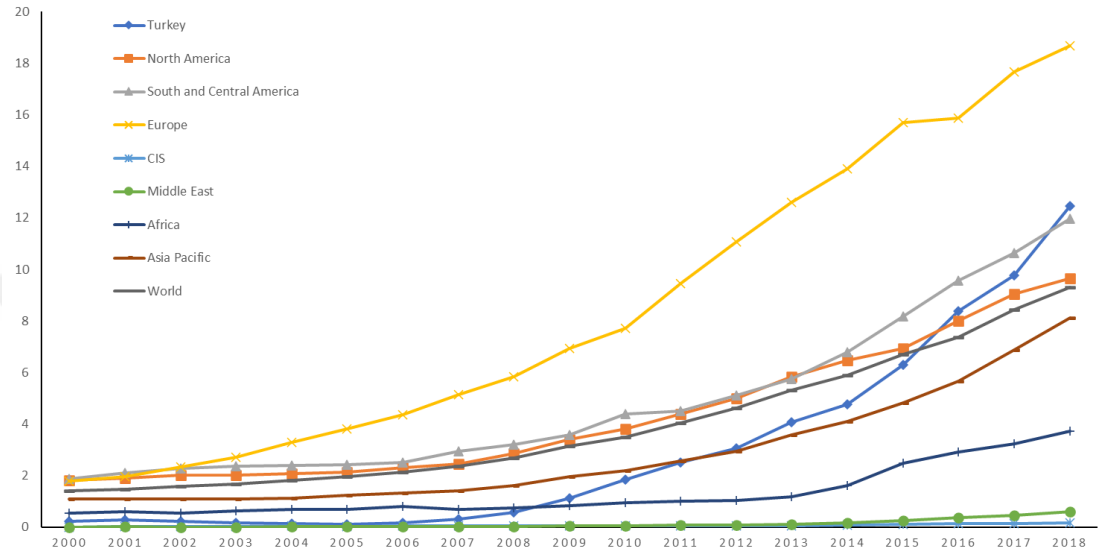


Figure 1. Renewables share of electricity generation worldwide

Source: BP Statistical Review 2019, a data set for 1965-2018

Again the same dataset published by BP, reveals that in 2018, the growth rate of solar generation in Turkey was 173 percent relative to the last year, while wind generation had increased 10.7 percent and renewable generation in total had increased 29.8 percent.

Figure 2 shows the current distribution of installation capacities of renewable generation sources in Turkey. Excluding reservoir and canal types hydropower generation plants, it is seen that solar and wind generation comprise the most of renewable generation, while the two are close in installed capacities.

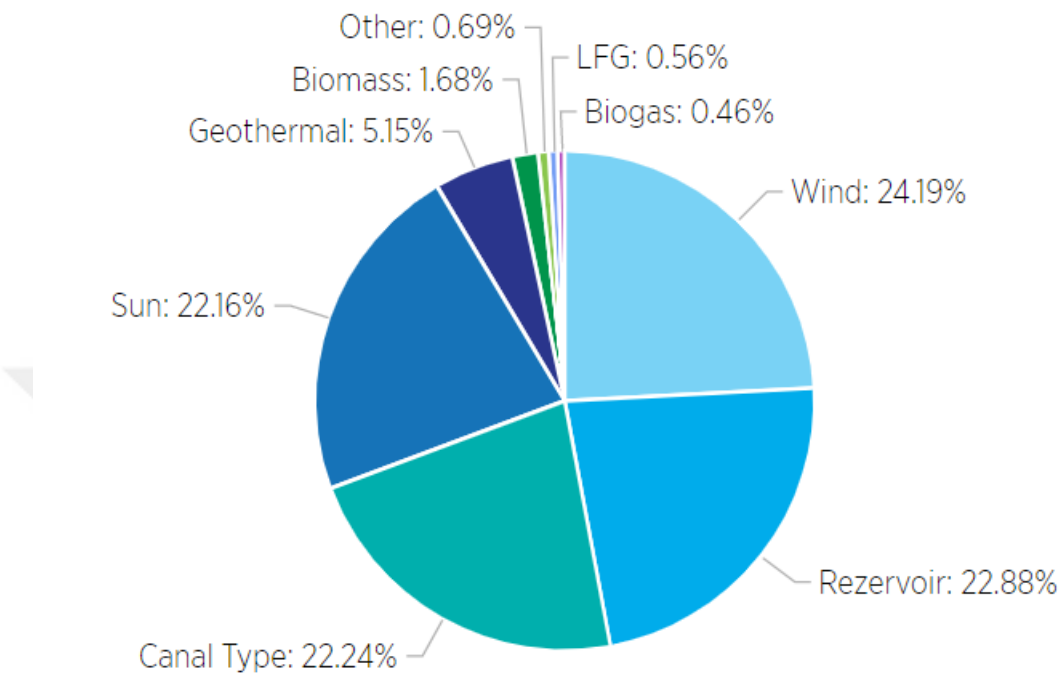


Figure 2. Renewable installation capacities in Turkey by March 2020 (including hydro)

Source: seffaflik.epias.com.tr

2.5 Modelling electricity markets and main discussions

Through the deregulation process in Europe and America, or in other words, restructuring the electricity markets during 90'ies, economists and policy-makers have quested for the answers of important questions related to the ongoing transformation, such as the efficiency gains, the performance estimations, etc. of newly founded markets. One of the main issues in the minds of energy economists was the market power, which results in non-competitive market prices after deregulation.

2.5.1 Spot market design and the exercise of market power:

One of the early papers in the literature is an experimental study conducted by Hahn and Boening (1990), which is comparing single-price sealed bid auction and split-savings rule regarding how much the outcome diverges from the competitive equilibrium. In split-savings mechanism, bids and offers are sorted and the highest bid and the lowest offer are matched, and the price is their average. Single-price sealed-bid mechanism works like a uniform auction mechanism explained above in the day-ahead spot market section. Conducting experiments, each one with four buyers and sellers, repeated three times, 24 experiments in total, they find deviations from CE are more likely under SS than SP, and SP rule is slightly more efficient although they both have above 90 percent efficiency. However, misrepresentation is less under the SS rule. Deviations get higher if one of the parties misrepresents more. (Hahn and Boening 1990)

Green and Newbery (1992) applied Klemperer and Meyer's (1989) supply function equilibrium model on British electricity markets assuming that many bids for electricity loads can be thought to compose a continuous supply function. Theoretical results imply high markups on marginal costs leading to substantial deadweight losses. They simulate the effect of entry which reduces the prices. However, they criticize the deregulation policy of the British government at the time of privatization that splits the electricity generation into two companies and then promotes the entry of new firms in the medium-run. They fit the theoretical model to the empirical reality of the British spot electricity market by data of the quantity produced, demand, price and costs of generators. With a social welfare analysis they find that instead of splitting the system into two and adding the new entrants to have an unregulated market, to split the generation into five companies and having a regulated quintopoly

would be more efficient in terms of social costs. In short, instead of expensive restructuring policies, better regulation of the system would have been preferable according to the authors.

Fehr and Harbord (1993) modeled the British wholesale electricity market as a first-price sealed-bid auction mechanism, which leads to the Nash equilibrium of prices well above the firms' marginal costs. They suggest and prove that if the market were designed as a second-bid auction mechanism, it would lead to marginal-cost pricing. They also show as an example that the two largest generators in the UK bid more than their marginal costs. Cost data is publicly available for the period in which the factories were government-owned. They have also criticized Green and Newbery (1992) claiming that bids of a company in the day-ahead market are not representing a continuous supply function, rather there are jumps between the bids which are reflecting discontinuity, which makes SFE modeling not appropriate according to them.

Catherine D. Wolfram (1998) holds an empirical analysis over Britain's electricity market finding that companies increase their price bids for supply to be paid more for their inframarginal capacities, and this effect is escalated for high marginal cost units. This can lead to an inefficient dispatch of plants, namely a more efficient plant may not be dispatched as frequently as it should be because of the high prices the company bids for it. Therefore, she is in favor of the discriminatory auctions.

Firms can also use the available capacity declaration as a market power exercise, by declaring high marginal cost units available first, for SMP to be determined highly. Also, under some spot market conditions, balancing dispatches when the demand is not met provides extra payments to firms for the additional capacity increases. Firms

can strategically plan which units will be made available in that case. Wolak and Patrick (2001) discuss these details in their working paper and argues that looking only at the bidding activity for market power exercise can be misleading.

Fabra, Fehr, and Harbord (2006) compare uniform and discriminatory auctions in a duopoly case, first assuming that firms offer horizontal bids which are a single price for their entire capacity, facing inelastic demand known with certainty by firms (short-lived bids), which can be justified for small periods by fixed prices of a retail market in a day. It is reasonable because the consumers do not respond to the bids in the spot markets in the short-run, but respond in a longer-run when the spot market prices affect the retail prices. Then the authors extend the model to price-elasticity, long-lived bids, multiple bids, and oligopoly cases and results are robust. The two equilibria are compared in terms of average prices and productive efficiency. In the certainty case, uniform auctions result in higher average prices. By this theoretical evidence, they claim that the adoption of discriminatory auction instead of the uniform auction for spot market mechanism in England in 2001 is one of the important factors behind the wholesale price reductions in 2001/2.

2.5.2 Contracts and the effect on market power

As mentioned above, electricity is traded in two stages: wholesale and retail. Since the relevant literature focuses on the competition between suppliers, the focal point is wholesale markets. Besides the spot market, suppliers can also sell their output through contracts of bilateral agreements, physical contracts, financial contracts, forward contracts, etc.. Therefore, contracts may have significant implications on modeling issues and decreasing effects on the exercise of market power.

Allaz and Vila (1993) models the market as a Cournot game and claims that the forward contracts are not only an issue of risk-hedging but also provide an opportunity to be the first mover through selling the future output and decreasing the future residual demand for the other firm. Therefore, turning the game into a Stackelberg version pushes the firms into a kind of prisoner's dilemma, when one of the firms is involved it is better of, but if the two are involved they are both worse off. Increasing the number of periods N between the contract and the actual realization of trade makes the outcome more competitive, reaching CE in the limit. However, Borenstein et al. (1995) mention that since the forward markets are repeated every other hour, duopoly firms can cooperate over contracts and punish each other for deviations, leading to even higher prices and less output than before. Thus, by itself, contracts' effect is ambiguous, however, they claim that due to the arbitrage condition there should not be a significant effect of contracts over modeling issues. If the prices in one of the two instruments (spot market and contracts) are higher, buyers substitute with the other, finally neutralizing the difference. Thus, they can be assumed as perfect-substitutes for each other.

Newbery (1998) applied a contract extended version of the SFE model and showed that the incumbents can increase their contract cover to deter entry if they have enough spare capacity, which in turn leads to price reductions in the spot market because of more competitive behavior of incumbents. Green (2003) also applied the SFE model with the extension of contracts to England and Wales, finding that, due to risk-averse buyers, contract markets may even have higher prices due to hedging risk of uncertainty.

2.5.3 Empirical works on market power

Catherine D. Wolfram (1999) holds an empirical analysis over British markets and finds that although the companies charge prices well-above marginal costs, they do not exploit the inelastic demand fully. Thus, the prices are below the oligopoly models' predictions. Suggested reasons are firms' behavior to escape regulatory action and the threat of entry. She finds that little support for the effects of contracts.

Borenstein and Bushnell (2003) model the California electricity markets as a static Cournot equilibrium and empirically assess the market power potential. They claim that using equilibrium models such as Cournot estimates the issue of market power more accurately and detailly than using concentration indexes such as HHI, which was regulators' preferred method at that time. Using two state-owned plants' cost data, they simulate a Cournot game, concluding that in cases of high and inelastic demand periods there is a substantial potential for market power. They also find that above-average hydroelectric conditions and integrated regional transmission decrease the severity of market power.

Prices went three times up in California in 2000 summer. Borenstein et al. (2002) provide two reasons for the trend: rising input cost which would have increased the prices even the market was competitive and retail market's inability to receive the price signals in the wholesale market which causes demand inelasticity in the short run.

2.5.4 Comparison of models: Bertrand, Cournot, and sfe

There are three categories of methods to model the electricity markets: equilibrium, optimization, and simulation models. Within the equilibrium models, there are three models mostly used: supply function equilibria, Cournot and auction models. In the

SFE model, producers submit their quantities as a function of price, and the model produces a range of equilibria bounded by Cournot and Bertrand. It is more difficult to solve SFE models, especially with increasing complexities reflected in the model, and it does not specify a unique outcome. However, using the Cournot may result in the overestimation of market power. Whether the Bertrand or the Cournot is best to use is discussed in the literature. The Bertrand equilibrium is based on the assumption of pricing below others to capture the entire demand. Due to the capacity constraints and increasing marginal costs near to full-capacity use, it is not appropriate to use it in the electricity context. Thus, quantity setting models are more appropriate for modeling electricity market oligopolies instead of price setting. (Borenstein and Bushnell 2003)

Willems et al. (2009) use German electricity market data to compare Cournot and the SFE models. They find that although in the long-run SFE models are more robust, they are difficult to solve with the added complexities. Besides, the Cournot model can be calibrated to fit the data by adjusting the forward contracts' shares, leaving the firms with less residual demand. Using the Cournot with suggested calibrations does not lead to considerable losses in the analysis. While the import-dependency of a market increases and the concentration decreases, the two models' performances get close, due to the relatively increasing demand elasticity.

2.5.5 Supporting mechanisms for renewables

Policy-makers have some instruments to cope with negative externalities of fossil-fuel-based energy production such as carbon taxes, mandates, direct subsidies, quotas, etc.. These instruments, either to tax brown energy or to support green energy, can be categorized into two types: market-based, (pricing externalities) and

non-market based (subsidies, technology mandates) policies. There are advocates for both policies. Supporters of market-based policies argue that subsidies are not efficient due to three reasons: first, it leads to underpricing of non-renewable energy and consequently to overconsumption, second, it does not displace brown energy efficiently, such as whether the natural gas or coal plants will be displaced out of subsidy policy, thirdly, the displacement may not result in the targeted local area. (Borenstein 2012)

The proponents of non-market based policies argue that market-based policies can be exploited by the incumbents and subject to a market power exercise, which will lead to insufficient levels of renewable generation in the system. For instance, designing a green-certificates market and requiring a minimum green energy quota on electricity consumption, the government can leave the pricing of green energy to the market with the hope that the market determines the true value of the externality. Fehr and Ropenus (2017) show that such a design allows the large incumbent companies to temporally involve in the renewable sector, to decrease the certificate prices by increasing their green energy production below entrants' marginal costs, and finally to deter entry in the long-run.

Butler and Neuhoff (2008) compare three mechanisms to promote wind installations by looking at the UK and Germany cases: feed-in tariff, quota, and auction. While the UK applied a tradable green certificate mechanism, Germany applied a feed-in tariff. They assess the idea of subsidizing green energy is more costly than market-driven mechanisms to promote it and reach that it is not true. Germany has been able to sustain cheaper prices per wind energy, to deploy more wind energy installations, and even to have a more competitive mechanism. They

have surveyed project developers to measure the competition they feel, and claim that competition level in Germany is not below the UK.

There is a paper by Ropenus and Jensen (2009), first presented to the 2008 IAEE(International Association for Energy Economics) conference in Istanbul, which deals with the relation of the vertical integration and fixed feed-in tariff. They use a non-renewable generating monopoly and a renewable generating fringe, with the extensions of two cases: comparison between vertical integration and unbundling, and the monopoly producing renewable too. In vertical integration, the monopoly exploits the fringe's profits, causing less provision of renewables. This effect is stronger if the monopoly can also produce renewable energy.

Feed-in tariff mechanisms can be integrated into the market mechanism as well, by outlining a premium tariff instead of a fixed one. Couture and Gagnon (2010) introduce and compare different types of FiT (feed-in tariff), as market dependent and independent versions. There can be caps that a premium added price can reach or floor prices to keep green energy generators revenue within a range. Rodriguez and Haas (2012) compare fixed and premium tariffs with calculations based on the Spanish electricity market between 2004-2009, in terms of profitability and the burden on consumers for each technology of renewable generation that was present in Spain during that time interval. They conclude that generally, the premium tariff is preferable due to its adaptation to the demand. Since fixed-feed in tariff is less risky for the investors, it can be preferred for non-mature technologies and small-scale projects such as house type solar installations.

As a case showing the handicaps of market-based support mechanisms, Newbery (2012) states that Britain was having difficulty in reaching the renewable targets, and sustaining energy security because the market mechanism lowers the

carbon price and the nuclear power generation plants were suffering from it. He also suggests that available capacity subsidies should be preferred instead of output payments, to foster the innovation by encouraging the investments, to decrease the risks affecting future prices, and to establish more efficient location choices. He also evaluates the Energy White Paper (issued by Department of Energy and Climate Change in 2011), which is suggesting a FiT mechanism combined with CfD (Contracts-for-Difference), in which the generator sells its output at a market price but compensated for below CfD value and pays back the positive difference, whose reference value should be set technology-specific. The author concludes that two-sided CfD is appropriate for controllable installations such as nuclear but not for the intermittent generation like wind or solar, which needs a less risky instrument like a FiT to prevent inefficient estimation costs. FiTs can also be thought of as contracts that are decreasing the risk for generators.

Andor and Voss (2016) propose a partial equilibrium model to analyze capacity and generation subsidies' optimality, and they claim that capacity subsidies (such as investment tax excerpts) should be equal to spillover effects (external benefit of green energy investments), and generation subsidies (such as the FiT) should be equal to greenhouse gas reductions (externality of green energy generation).

2.5.6 DG's effect on the price

Mulder et al. (2015) use a Cournot model extended with a structural market model of the Dutch electricity market, to measure the effect of fringe generation (wind and horticultural farmers' CHP generators) on the electricity prices. While the wind generation's effect on prices is stronger than CHP plants, both lower the prices slightly.

CHAPTER 3

THE MODEL:NON-RENEWABLE ELECTRICITY PRODUCING DOMINANT FIRM AND RENEWABLE COMPETITIVE FRINGE

We use the framework presented by der Fehr and Ropenus (2017) with some alterations and extensions. We assume a linear demand for electricity $D(p) = A - Bp$, which implies that electricity demand is not inelastic, and $A, B > 0$. I also assume that the demand and the supply are simultaneously equated. This assumption, although it is common in the economics discipline, is even more crucial for the electricity sector. Because of the difficulty of transmitting and storing electric power, regulatory institutions in countries with well established electricity market, try their best to maintain equality of demand and supply in the electricity grid.

The basic model consists n number of dominant firms that are generating non-renewable electricity denoted by (Q_i^D) and a competitive fringe of a price-taker firm generating renewable electricity denoted by (Q^F). Non-renewable electricity producing dominant firms are indexed by $i \in [1, n]$, and by M when there is one dominant firm; a monopoly. Cost of generating non-renewable electricity for dominant firms is $C_i^D = c_i^D Q_i^D$ where $c_i^D > 0$ and it reflects a unit cost function. Cost of generating renewable electricity for the competitive fringe is $C^F = c^F Q^F + (1/2) d^F (Q^F)^2$ where $c^F > 0$ and $d^F > 0$ reflects a quadratic cost function. Generating renewable electricity is more costly than non-renewable electricity, which is reflected in $c^F \geq c_i^D$. On the other hand generating non-renewable electricity has a negative externality on the environment reflected as γQ^2 with $\gamma > 0$ where $Q = \sum_{i=1}^{n} Q_i^D$ denotes the total output of dominant firms and $c = \sum_{i=1}^{n} c_i^D$ denotes the sum of their cost parameters.

The analysis theoretically works in three stages: first the government sets the optimal tariff by maximizing the social welfare function, then the dominant firms (or the firm in the monopoly case) solve their profit maximization problems as Cournot players towards each other, and collectively as a Stackelberg leader towards the fringe, then the fringe solves its problem taking the market price as given. We solve the model backwards starting from the fringe's problem, and then the dominant firms' problems finding their best response functions $Q_i^{D^e}$ and then the social welfare maximization will be held in which the optimal amount of tariffs will be found in terms of the parameters $A, B, c_i^D, c^F, d^F, \gamma$.

The model is solved for heterogeneous costs for N number of dominant firms, and then the specific case of the Cournot duopoly and the fringe equilibrium is outlined. However, we will first present the solutions for the monopoly and the fringe case, because it has most of the insights we can extract from the n firms case and easier to interpret. When we present the solutions of n dominant firms cases, the notation of the demand function will slightly be changed to $D = \dfrac{a-p}{b}$ for describing the Cournot game more smoothly.

For each cases, namely the different numbers of dominant firms, there are two sub-cases: fixed feed-in-tariff and premium-feed-in tariff, where in the fixed FiT case, the fringe is paid $T \geq 0$ and in the premium tariff case the fringe is paid a premium $\tau \geq 0$ on top of the price: $p + \tau$. Besides, $\overline{\tau}$ denotes the critical value for the premium tariff to lead positive fringe outcome.

3.1 Non-renewable electricity producing monopoly and renewable competitive fringe with fixed feed-in-tariff

In the first case, the competitive fringe that produces renewable energy is paid a fixed tariff $T \geq 0$. Fixed tariff as a support mechanism is prevalent in the countries like Germany and Turkey to incentivize renewable energy investments.

Price taker firm in the competitive fringe maximizes profit:

$$\pi^F = TQ^F - C^F(Q^F) \tag{1}$$

The first order condition with respect to quantity produced results in:

$$T = c^F + d^F Q^F \tag{2}$$

Equation 2 gives the critical value for the fringe production. For $T \leq c^F$ the effective tariff is zero, meaning that there is no fringe output. Since the fringe output is only dependent on the tariff value, it is independent of the monopoly decision.

Profit maximization problem of the conventional monopoly (producing non-renewable electricity only)

$$\pi_M^D = pQ_M^D - C_M^D(Q_M^D) \tag{3}$$

$$= p(D(p) - Q^F(T)) - C_M^D(D(p) - Q^F(T)) \tag{4}$$

The first order condition with respect to the price to be set by the monopoly results in:

$$(D(p) - Q^F(T)) + p(D^{'} - Q^{F^{'}}(T)) - C_M^{D^{'}}(D^{'} - Q^{F^{'}}(T))) = 0$$

Letting $\varepsilon_{DF} = \frac{-p^{'}(D^{'}-{Q^F}^{'}(T))}{(D(p)-Q^F(T)}$ stand for the price elasticity of the residual demand for the monopoly the first order condition above can be rearranged as:

$$p(1 - \frac{1}{\varepsilon_{DF}}) = c_M^D \tag{5}$$

Rewriting 2, we find that $Q^F = \frac{T - c^F}{d^F}$. The fringe does not supply unless T is above c^F and the whole demand is met by the monopoly firm. Then the effective fixed tariff would be equal to zero. Therefore it can be taken as a boundary condition for the fixed tariff. Plugging Q^F and $(Q^F)^{'}$ into ε_{DF} we reach that $\varepsilon_{DF} = \frac{pB}{(A - pB - \frac{T-c^F}{d^F})}$. Plugging the elasticity of residual demand into 5, we find:

$$\begin{aligned} c_M^D =& p(1 - \frac{A - Bp - \frac{T-c^F}{d^F}}{Bp}) \\ p =& \frac{c_M^D + \frac{A}{B} - \frac{T-c^F}{Bd^F}}{2} \end{aligned}$$

Monopoly output is then easy to calculate by plugging the above price equation into the demand function and extracting the fringe output:

$$\begin{aligned} D =& \frac{A}{2} - \frac{Bc_M^D}{2} + \frac{T - c^F}{2d^F} \\ Q^F =& \frac{T - c^F}{d^F} \\ Q_M^D =& \frac{A}{2} - \frac{Bc_M^D}{2} - \frac{T - c^F}{2d^F} \end{aligned}$$

It is seen that total demand is increasing and monopoly output is decreasing in T. It is expected due to the decrease in price as fixed tariff increases.

Social welfare function is composed of total profits (producer surplus), consumer surplus, socialized cost of the tariff (which is exogenous to the electricity consumer's decision therefore not affecting the demand directly), and the environmental externality of non-renewable electricity production.

$$SWF = TQ^F - C^F(Q^F) + pQ_M^D - C_M^D(Q_M^D) + \frac{D^2}{2B} - (T-p)Q^F - \gamma(Q_M^D)^2$$

Maximizing SWF with respect to T will give the optimal amount of fixed tariff T in terms of the parameters.

Case 1: Below the critical value $T = c^F$ the effective fixed tariff will be zero, therefore the monopoly will cover the whole market. The social welfare reached by only monopoly production should be taken as a threshold for the social welfare reached by the optimal tariff:

$$SWF_1 = p(D(p)) - C_M^D(D(p)) + \frac{D^2}{2B} - \gamma(Q_M^D)^2$$

Case 2: $T > c^F$ and the fringe output is positive:

$$SWF_2 = TQ^F - C^F(Q^F) + pQ_M^D - C_M^D(Q_M^D) + \frac{D^2}{2B} - (T-p)Q^F - \gamma(Q_M^D)^2$$

Maximizing SWF with respect to T, we find the optimal tariff:

$$T^* = \frac{c^F + 3Bc_M^D d^F + Ad^F + 2\gamma(ABd^{F^2} - c_M^D d^{F^2} B^2 + c^F B d^F)}{1 + 4d^F B + 2\gamma B}$$

T increases as c^F increases, which means a higher tariff is needed to mitigate the negative externality while producing renewable is getting more costly, however it may reach to a point where the fringe output is more costly than the negative externality of the non-renewable generation. That should be checked by whether $SWF_2 > SWF_1$, if not; the corner solution exists which means that the optimal fixed tariff is zero.

3.2 Non-renewable electricity producing monopoly and renewable competitive fringe with premium feed-in-tariff

Premium tariff mechanism is not as much market-based as green certificates, and not as direct as fixed tariff. In this support scheme, there is an opportunity for the incumbent firm to effect the net price of renewable energy generation, and to mitigate the effects of its entry. In this case, the renewable competitive fringe is paid a premium over the price: $p + \tau$, with $\tau >= 0$.

Price taker firm in the competitive fringe maximizes profit:

$$\pi^F = (p + \tau)Q^F - C^F(Q^F) \tag{6}$$

The first order condition with respect to quantity produced results in:

$$p + \tau = c^F + d^F Q^F \tag{7}$$

$$Q^F = \frac{p + \tau - c^F}{d^F} \tag{8}$$

Profit maximization problem of the non-renewable electricity producing monopoly:

$$\pi_M^D = p(D(p) - Q^F(p+\tau)) - C_M^D(D(p) - Q^F(p+\tau)) \tag{9}$$

The first order condition with respect to p results in:

$$(D(p) - Q^F(p+\tau)) + p(D^{'} - Q^{F^{'}}(p+\tau)) - C_M^{D^{'}}(D^{'} - Q^{F^{'}}(p+\tau)) = 0 \tag{10}$$

Solving the equation 10 further and plugging the elasticity of residual demand in it we find:

$$p(1 - \frac{1}{\varepsilon_{DF}}) = c_M^D \tag{11}$$

Plugging the price elasticity of the residual demand $\varepsilon_{DF} = \frac{p(-B-(1/d_R)}{-(A-Bp-(p+\tau-c_R/d_R)}$ in 11 we find:

$$c_M^D = p(1 + \frac{A - Bp - \frac{\tau - c^F}{d^F}}{(-B - \frac{1}{d^F})p}) \tag{12}$$

$$c_M^D = \frac{p(B + \frac{1}{d^F}) - A + Bp + \frac{p}{d^F} + \frac{\tau - c^F}{d^F}}{2(B + \frac{1}{d^F})} \tag{13}$$

$$p = \frac{c_M^D(B + \frac{1}{d^F}) + A - \frac{\tau - c^F}{d^F}}{2(B + \frac{1}{d^F})} \tag{14}$$

$$p = \frac{c_M^D}{2} + \frac{A}{2(B + \frac{1}{d^F})} - \frac{\tau - c^F}{2(Bd^F + 1)} \tag{15}$$

$$\frac{dp}{d\tau} = \frac{-1}{2(B + \frac{1}{d^F})} \tag{16}$$

Monopoly can deter entry by lowering the prices till the equation 15, thus the critical value for the premium tariff to lead to the positive fringe output is given by the below equations:

$$\begin{aligned}\tau \leq & c^F - p \\ \tau \leq & c^F - \frac{c_M^D}{2} - \frac{A}{2(B + \frac{1}{d^F})} + \frac{\tau - c^F}{2(Bd^F + 1)} \\ \overline{\tau} = & c^F - \frac{c_M^D B d^F + c_M^D + A d^F}{2Bd^F + 1}\end{aligned}$$

Therefore, as long as τ is below $\overline{\tau}$, the monopoly finds it optimal to deter the fringe's entry. Above this value on the other hand, monopoly finds it optimal not to deter the fringe's entry. Then, as the premium paid to the fringe increases, monopoly price decreases.

We can get the demand function straightforwardly from the price equation:

$$D(p) = \frac{A(Bd^F + 2)}{2(Bd^F + 1)} - \frac{Bc_M^D}{2} + \frac{B(\tau - c^F)}{d^F} \tag{17}$$

Equilibrium output to be produced by the fringe and the monopoly are then found by plugging 15 into 8 and then extracting the fringe output from total demand:

$$Q^F = \frac{A}{2(Bd^F + 1)} + \frac{c_M^D}{2d^F} + \frac{(2Bd^F + 1)(\tau - c^F)}{2d^F(Bd^F + 1)} \tag{18}$$

$$Q_M^D = \frac{A}{2} - \frac{(Bd^F + 1)c_M^D}{2d^F} - \frac{(\tau - c^F)}{2d^F} \tag{19}$$

Total demand and the fringe output are increasing and the price and monopoly output are decreasing in τ. Thus as τ increases, the consumer surplus, the fringe

profit, and the socialized cost of tariff increase while monopoly profit and the external cost on environment decrease.

Case 1: As long as $\tau \leq \overline{\tau}$ then there is only monopoly output, thus the SWF is:

$$SWF_1 = p(D(p)) - C_M^D(D(p)) + \frac{D^2}{2B} - \gamma {Q_M^D}^2$$

Case 2: If $\tau > c^F - \overline{\tau}$, then the fringe output is positive:

$$SWF_2 = (p+\tau)Q^F - C^F(Q^F) + p(D(p) - Q^F) - C_M^D(D(p) - Q^F) + \frac{D^2}{2B} - (\tau)Q^F - \gamma {Q_M^D}^2$$

Maximizing the social welfare function with respect to τ, optimal amount of premium is found, and it is given by the proposition below:

$$\tau^* = \frac{(2\gamma(Bd^F + 1) - d^F)(Ad^F - c_M^D(Bd^F + 1) + c^F)}{2\gamma(Bd^F + 1) - d^F + 4Bd^F + 2} \tag{20}$$

It should again be checked for the corner solution whether $SWF_2 < SWF_1$ or not. In that case then the optimal premium tariff is zero because the cost of tariff is higher than the negative externality caused by monopoly.

3.3 N firm Cournot oligopoly and renewable competitive fringe with fixed feed-in-tariff

In this section I will briefly present the solution of optimal fixed FiT under n firm Cournot oligopoly that produce non-renewable electricity, and the competitive fringe selling the electricity it produced at the fixed tariff, T, independent of the market price. Oligopoly firms are indexed by i. The sum of oligopoly output is Q and the sum of these firms' marginal costs is equal to c: $(Q = \sum_{i=1}^{n} Q_i^D)$, $(c = \sum_{i=1}^{n} c_i^D)$.

The costs of Cournot firms are not considered equal in this part, however in the simulation part below, they will be set equal to 0.2.

Profit maximization problem of the price taker firm (competitive fringe):

$$\pi^F = TQ^F - C^F(Q^F)$$

The first order condition with respect to Q^F results in:

$$T = c^F + d^F Q^F \tag{21}$$

$$Q^F = \frac{T - c^F}{d^F} \tag{22}$$

The critical value for fixed tariff is $T = c^F$ below which there is no fringe output.

Profit function of one of the symmetric duopoly firms;

$$\pi_i^D = pQ_i^D - C_i^D(Q_i^D)$$

Taking its derivative with respect to Q_i^D gives us the best response functions of firms to each other, and summing these equations for all n gives us the equation 25, then the value of Q^F is plugged in it to find the Q in terms of T and the other parameters;

$$0 = a - bQ_i^D - bQ - bQ^F - c_i^D \tag{23}$$

$$0 = an - bQ - bnQ - c - bnQ_F \tag{24}$$

$$Q = \frac{an}{b(1+n)} - \frac{n(T - c^F)}{(1+n)d^F} - \frac{c}{b(1+n)} \tag{25}$$

Using best response function of firm i, we can find Q_i^D in the equilibrium:

$$Q_i^D = \frac{a + c - (1+n)(c_i^D)}{b(1+n)} - \frac{(T - c^F)}{d^F(1+n)} \tag{26}$$

The price is then found by the assumption that the supply and the demand are equal to each other; Total demand is equal to;

$$\begin{aligned} D(p) =& \frac{a-p}{b} \\ =& Q + Q^F \\ =& \frac{(an-c)d^F + (T - c^F)}{d^F b(1+n)} \end{aligned}$$

Plugging the proposition above into the price equation results in:

$$p = a - b(Q + Q^F) \tag{27}$$

$$p = \frac{ad^F + cd^F - b(T - c^F)}{d^F(1+n)} \tag{28}$$

Total demand and the fringe output are increasing, and price and monopoly output are decreasing in the fixed tariff.

Case 1: $T \leq c^F$, there is no fringe output and the oligopoly covers the all demand:

$$SWF_1 = (\sum_{i=1}^{n} pQ_i^D - c_i^D Q_i^D) + \frac{bQ^2}{2} - \gamma Q^2$$

Case 2: $T > c_R$, fringe output is positive

$$SWF_2 = (\sum_{i=1}^{n} pQ_i^D - c_i^D Q_i^D) + \pi^F + \frac{b(Q+Q^F)^2}{2} - (T-p)Q^F - \gamma(Q)^2$$

maximizing it with regard to T, optimal level of T is found and it is given in the proposition below:

$$T^* = \frac{ad^F + (2+n)(c)d^F + bc^F + \gamma(\frac{2n^2ad^F - 2n(c)d^F}{b} + 2n^2c^F)}{n^2d^F + 2nd^F + b + d^F + 2n^2\gamma}$$

If $SWF_2 > SWF_1$, T^* is the optimal (interior) solution, otherwise corner solution exists meaning that the optimal fixed tariff is zero.

Plugging 2 instead of n into the n-firm case general solutions above, equilibrium price, outputs and the optimal fixed tariff can be found for duopoly and the fringe with the fixed tariff:

$$\begin{aligned}
Q_i &= \frac{a}{3b} + \frac{c_{-i}^D - 2c_i^D}{3b} - \frac{T-c^F}{3d^F} \\
Q &= \frac{2a}{3b} - \frac{c}{3b} - \frac{2(T-c^F)}{3d^F} \\
Q_F &= \frac{T-c^F}{d^F} \\
p &= \frac{ad^F + cd^F - b(\tau - c^F)}{d^F(1+n)} \\
T^* &= \frac{ad^F + 4(c_i^D + c_{-i}^D)d^F + bc^F + \gamma(\frac{8ad^F - 4(c_i + c_{-i})d^F}{b} + 8c^F)}{b + 9d^F + 8\gamma}
\end{aligned}$$

Case 1: $\tau \leq c^F$, there is no fringe output:

$$SWF_1 = \pi_i^D + \pi_{-i}^D + \frac{b(Q_i^D + Q_-^D i)^2}{2} - \gamma(Q_i^D + Q_-^D i)^2$$

Case 2: $\tau > c^F$, fringe output is positive

$$SWF_2 = \pi_i^D + \pi_{-i}^D + \pi^F + \frac{bD^2}{2} - (T-p)Q^F - \gamma(Q_i^D + Q_{-i}^D)^2$$

If $SWF_2 > SWF_1$, T^* is the optimal (interior) solution, otherwise corner solution exists meaning that the optimal fixed tariff is zero.

3.4 N Firm Cournot oligopoly and renewable competitive fringe with premium feed-in-tariff

The profit maximization problem of the Cournot firms:

$$\pi_i^D = pQ_i^D - C_i^D(Q_i^D)$$

However, the price at which the fringe sells renewable electricity depends on the market price set by the Cournot players: $p + \tau$. Therefore the critical value for the fringe output to be positive will consider the sum of premium and the price set by the Cournot players that behave *à la* Stackelberg leaders and the fringe as a follower.

Profit maximization problem of the fringe:

$$\pi^F = (p+\tau)Q^F - C^F(Q^F)$$

The first order condition with respect to Q^F results in:

$$(p+\tau) = c^F + d^F Q^F \tag{29}$$

$$Q^F = \frac{(p+\tau) - c^F}{d^F} \tag{30}$$

The fringe output is dependent on the price, and thus the production decisions of Cournot players will effect the fringe's decision, and Cournot players will consider this in their profit maximization:

$$p = a - b(Q + Q^F) \tag{31}$$

$$Q^F = \frac{a - b(Q + Q^F) + \tau - c^F}{d^F} \tag{32}$$

$$Q^F = \frac{\tau - c^F + a - b(Q)}{b + d^F} \tag{33}$$

It follows that $\frac{dQ^F}{dQ_i^D} = \frac{-b}{b+d^F}$. Profit function of one of the symmetric Cournot firms:

$$\begin{aligned}
\pi_i^D &= pQ_i^D - C_i^D(Q_i^D) \\
\pi_i^D &= Q_i^D(a - b(Q_i^D + Q_-^D i^e + Q^F)) - C_i(Q_i^D) \\
&= aQ_i^D - bQ_i^{D^2} - bQ_i^D Q_-^D i^e - bQ_i^D Q^F - c_i^D Q_i^D
\end{aligned}$$

Taking its derivative with respect to Q_i;

$$0 = a - bQ_i^D - bQ - bQ^F - bQ_i^D \frac{dQ^F}{dQ_i^D} - c_i^D \tag{34}$$

$$= a - bQ - bQ^F - bQ_i^D - bQ_i^D \frac{-b}{b+d^F} - c_i^D \tag{35}$$

Summing the equation 35 over all $i = 1, ..., n$, and plugging the equation 33 in it we find total Cournot output $Q = \sum_{i=1}^{n} Q_i^D$ that is given in the proposition below:

$$Q = \frac{an}{(1+n)b} - \frac{c(b+d^F)}{(1+n)bd^F} - \frac{(n(\tau - c^F)}{(1+n)d^F}$$

By plugging the proposition above for Q in the equation 33 we find Q^F, and plugging Q^F and Q into the best response function of firm i, 35, we find Q_i^D:

$$\begin{aligned} Q^F =& \frac{ad^F + c(b+d^F) + ((1+n)d^F + bn)(\tau - c^F)}{(1+n)d^F(b+d^F)} \\ Q_i^D =& \frac{ad^F - b(\tau - c^F) + c(b+d^F) - (1+n)(b+d^F)c_i^D}{(1+n)bd^F} \end{aligned}$$

Plugging the sum of produced quantities Q, Q^F into the demand equation:

$$p = a - b(Q + Q^F) \tag{36}$$

$$p = \frac{ad^F - b(\tau - c^F) + c(b+d^F)}{(1+n)(b+d^F)} \tag{37}$$

$$\frac{dp}{d\tau} = -\frac{b}{(1+n)(b+d^F)} \tag{38}$$

$$\frac{dD}{d\tau} = \frac{1}{(1+n)(b+d^F)} \tag{39}$$

Plugging the equation 37 in 30 we find the critical value for the premium, above which the fringe output is positive:

$$\overline{\tau} = c^F - \frac{ad^F + (b+d^F)c}{(bn + nd^F + d^F)}$$

The social welfare function is same with the other parts; Case 1: $\tau \leq \overline{\tau}$, there is no fringe output:

$$SWF_1 = pQ - (\sum_{i=1}^{n} Q_i^D c_i^D) + \frac{bQ^2}{2} - \gamma Q^2$$

Case 2: $\tau > \overline{\tau}$, fringe output is positive

$$SWF_2 = (\sum_{i=1}^{n} pQ_i^D - c_i^D Q_i^D) + \pi^F + \frac{b(Q+Q^F)^2}{2} - (\tau)Q^F - \gamma(Q)^2$$

maximizing it with regard to τ, optimal level of τ is found, that is given in the proposition below:

$$\begin{aligned}\tau^* =& \frac{-and^{F2} + c(b+d^F)d^F - nbc^F d^F}{2\gamma n^2(b+d^F) - nbd^F + (1+n)d^F((1+n)d^F + bn)} \\ &+ \frac{\gamma(2n^2 ad^F(b+d^F) - 2nc(b+d^F)^2 + 2bn^2 c^F(b+d^F))}{b(2\gamma n^2(b+d^F) - nbd^F + (1+n)d^F((1+n)d^F + bn))}\end{aligned}$$

If $SWF_2 > SWF_1$, τ^* is the optimal (interior) solution, otherwise corner solution exists meaning that the optimal premium tariff is zero.

Plugging 2 instead of n, we can find the equilibrium price and quantities, and optimal premium tariff for non-renewable electricity producing Cournot duopoly and renewable competitive fringe with the premium tariff:

$$
\begin{aligned}
\overline{\tau} =& c^F - \frac{ad^F + (b+d^F)(c_i^D + c_{-i}^D)}{(2b+3d^F)} \\
Q^F =& \frac{ad^F + c(b+d^F) + (3d^F+2b)(\tau - c^F)}{3d^F(b+d^F)} \\
Q_i^D =& \frac{a}{3b} + \frac{(c_i^D - 2c_{-i}^D)(b+d^F)}{3bd^F} - \frac{(\tau) - c^F}{3d^F} \\
p =& \frac{ad^F - b(\tau - c^F)}{3(b+d^F)} + \frac{b(c_i^D + c_{-i}^D)}{3} \\
\tau^* =& \frac{-2a{d^F}^2 + (c_i^D + c_{-i}^D)(b+d^F)d^F - 2bc^F d^F}{8\gamma b + 9{d^F}^2 + 4bd^F + 8\gamma d^F} \\
&+ \frac{\gamma 8ad^F(b+d^F) - 4\gamma(b+d^F)^2(c_i^D + c_{-i}^D) + 8\gamma bc^F(b+d^F)}{b(8\gamma b + 9{d^F}^2 + 4bd^F + 8\gamma d^F)}
\end{aligned}
$$

The social welfare function is same with the other parts:

Case 1: $\tau \leq \overline{\tau}$, there is no fringe output:

$$SWF_1 = \pi_i^D + \pi_{-i}^D + \frac{b(Q_i^D + Q_{-i}^D)^2}{2} - \gamma(Q_i^D + Q_{-i}^D)^2$$

Case 2: $\tau > \overline{\tau}$, fringe output is positive

$$SWF_2 = \pi_i^D + \pi_{-i}^D + \pi^F + \frac{bD^2}{2} - (\tau)Q^F - \gamma(Q_i^D + Q_{-i}^D)^2$$

If $SWF_2 > SWF_1$, τ^* is the optimal (interior) solution, otherwise corner solution exists meaning that the optimal premium tariff is zero.

CHAPTER 4

PARAMETRIC EXAMPLE AND THE SIMULATIONS: THE CASE OF TURKEY

Fixed feed-in-tariff and premium feed-in-tariff are compared on various settings: the monopoly and the fringe, and the different numbers of cournot oligopoly firms and the fringe. The two mechanisms are evaluated in terms of leading higher renewable generation levels, efficiency that is measured through the social welfare maximization and effects on competition.

Government choose a γ value, showing its valuation of the environmental externality reflected as the quadratic function of the non-renewable electricity generation. Then, the optimal tariff is found by social welfare maximization, considering the rational agents' responses. Therefore, the two mechanisms are compared in regard to their effects at the same γ level, meaning that the optimal scenario they would lead to under the same valuation level of the government for the environment.

The parameters that are used in this simulation are as following: $c_M^D = 0.2$, $c^F = 0.7$, $d^F = 1$, $c_i^D = 0.2$, $A = 1$, $B = 1$. The value of γ varies in the range: $[0.0, 3.0]$ to show the effects of the different levels of valuation for the environment under the two policies. The comparisons between the two policies (fixed and the premium tariffs) are held by comparing the prices, renewable and non-renewable energy quantities, total demand, total welfares; while keeping the decision maker's valuation of the environment same.

In the fourth section of this chapter, some relevant descriptive statistics of the Turkish electricity market will be presented, together with the story of how Turkish electricity market have developed. Then, the case of 18 non-renewable electricity

producing Cournot firms and the renewable competitive fringe, that coincides with the current concentration level of Turkish electricity markets will be examined to find which tariff mechanism should be preferred.

4.1 Fixed and premium tariffs, monopoly and the fringe

Figure 3 shows how the price, optimal fixed tariff, and quantities at the equilibrium change in response to a change in γ.

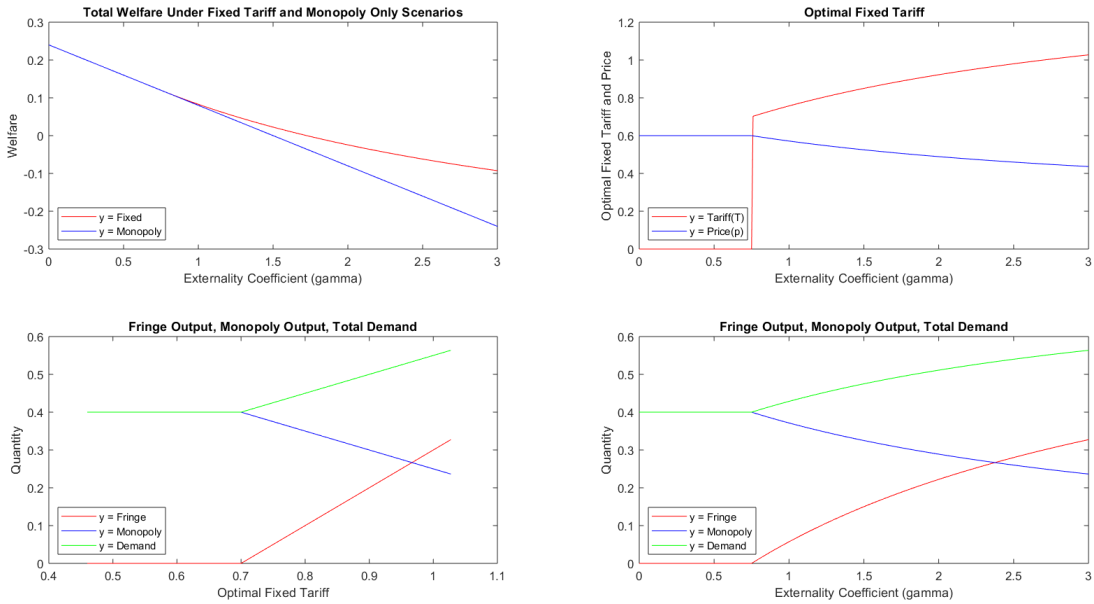


Figure 3. Fixed tariff, the monopoly and the fringe

Figure 4 shows how the price, optimal premium tariff, and quantities at the equilibrium change in response to a change in γ.

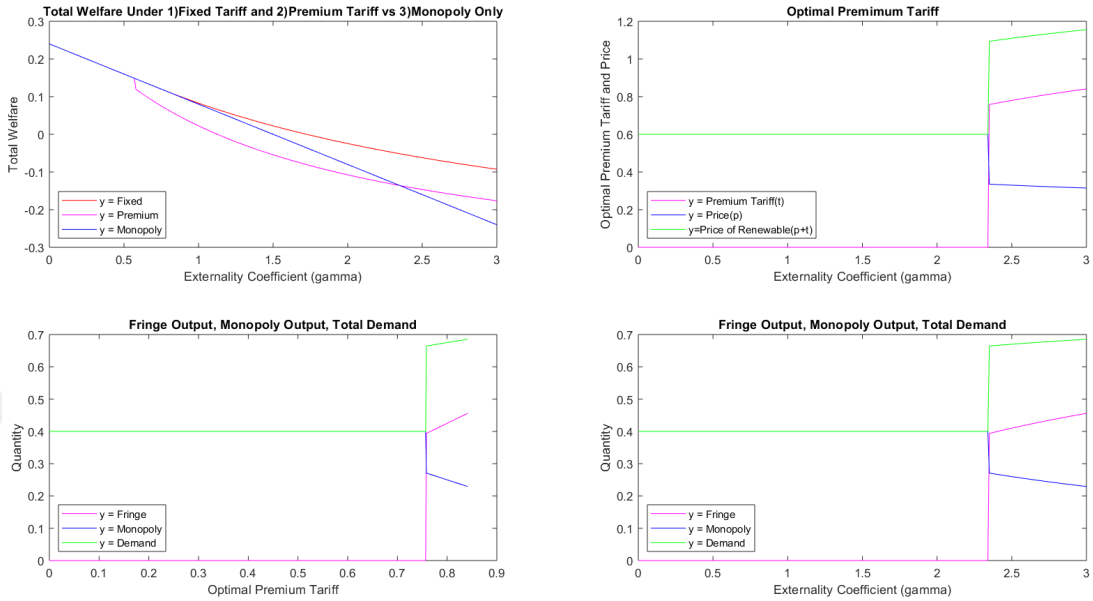


Figure 4. Premium tariff, the monopoly and the fringe

When the fixed tariff and the premium tariff are compared, it is seen that under the premium tariff until a specific gamma value above τ_2 (between 2-2.5), output of the fringe is zero because of the less social welfare is generated than the monopoly only scenario. The explanation for this is the market power of the monopolistic firm. Since it can effect the price of renewable electricity when the fringe is paid $p + \tau$, it cuts its price more than it would do in the case of the fixed tariff. Since the consumers face the market price because the tariff mechanism is exogenous, the total demand of electricity increases more than it does under the fixed tariff case while the fringe output is positive. For this reason, there is a higher rebound effect for the premium tariff, and it leads to higher socialized costs of renewable electricity generation. Therefore, there is an overconsumption of the renewable generation. Thus, it does not constitute a severe problem as it would do if it had led to the increase in the non-renewable generation.

For a government that only cares about the amount of social welfare generated in the economy, the premium tariff needs more valuation for the environment to be implemented compared to the fixed tariff. That can be seen from the fact that it generates less welfare than without the premium scenario (namely the monopoly domination) till a very high level of γ ($\gamma = 2.35$)compared to the fixed tariff ($\gamma = 0.75$), for the selected parameters. The premium tariff, although it leads to less social welfare than the fixed tariff, leads to higher renewable electricity generation which can be preferred if a faster development of renewable electricity facilities is desired.

As the number of dominant firms increase, their dominance decrease. This is expected to decrease their ability to effect the prices, meaning that the residual demand each firm covers shrink. Thus, the total conventional output increases, because of the decrease in the price and the increase in the demand as the number of firms increase. However, these effects should be compared in each scenario for more certain findings. Below, the Cournot cases of 2, 3 and 18 firms are analyzed.

4.2 Fixed and premium tariffs, Cournot duopoly and the fringe

Figure 5 shows how the price, optimal fixed tariff, and quantities at the equilibrium change in response to a change in γ.

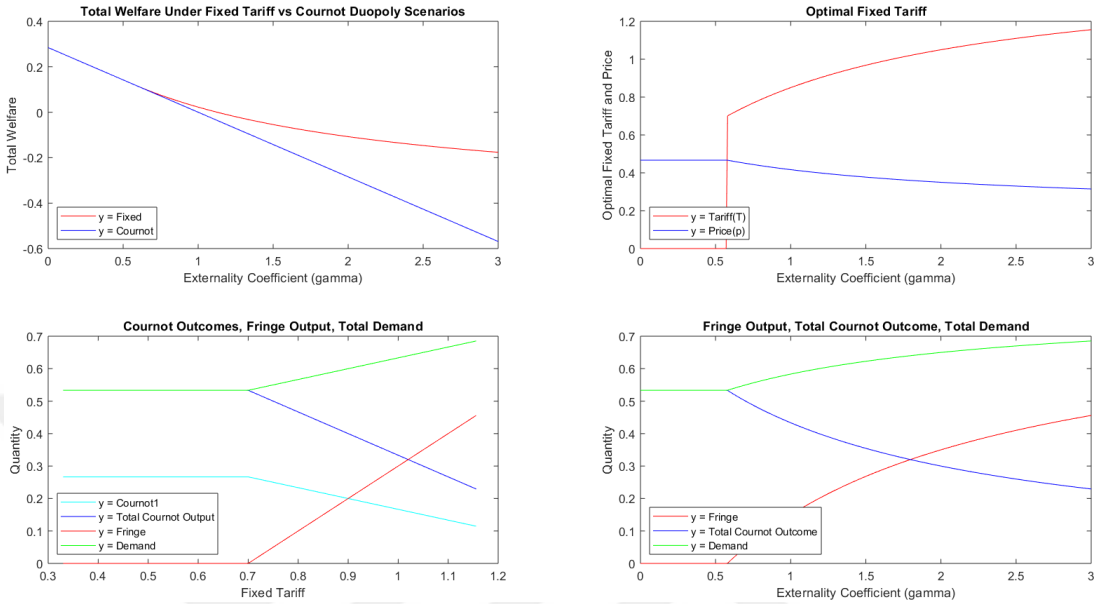


Figure 5. Fixed tariff, the Cournot duopoly and the fringe

Figure 6 shows how the price, optimal premium tariff, and quantities at the equilibrium change in response to a change in γ.

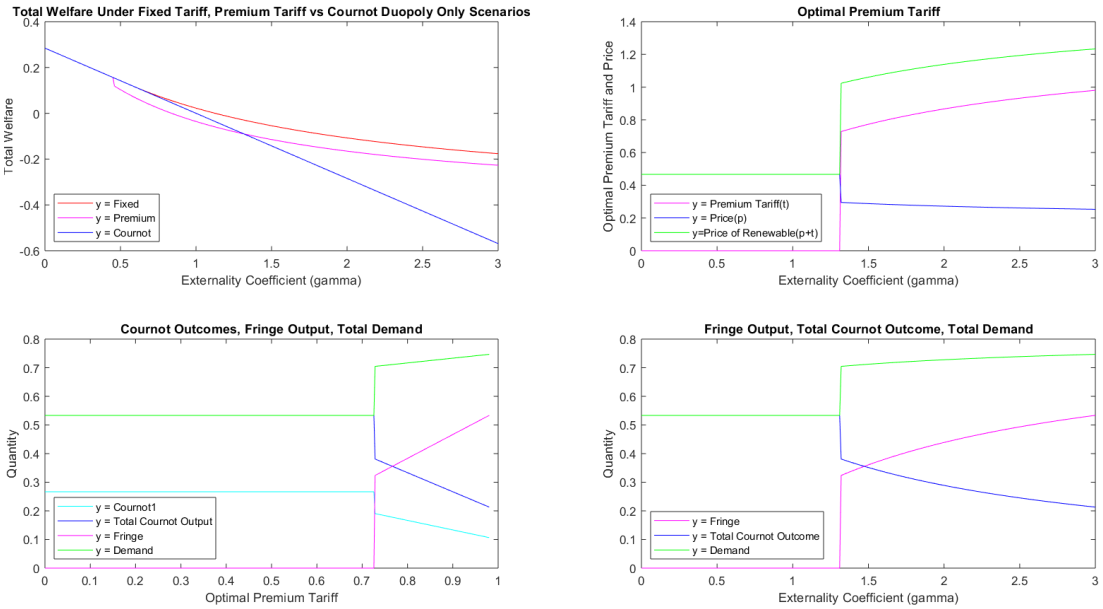


Figure 6. Premium tariff, the Cournot duopoly and the fringe

The same comments can be made for the Cournot duopolu model regarding the quantities and prices. For instance, lower prices of electricity in the premium tariff model, because of the Stackelberg leaders' move to cut their prices when faced the fringe entry, first to deter its entry, and then to increase their profits by increasing the residual demand they cover, and to make the fringe gets a lower price plus premium. This leads to a higher demand of electricity, which results in a rebound effect (although it is again covered by the increase in the renewable generation). However, since the market power of the incumbent firms is less relative to the monopoly case, they effect the price of renewable electricity at a less severe level. The decrease in the market price, and the increase in the demand are lower compared to the monopoly and the fringe scenario. Therefore we can conclude that as the number of incumbent firms increases, the difference in the social welfares of with and without fringe scenarios reached by the fixed and the premium tariff decreases and the two system approximate each other at the optimal level of tariffs.

The premium tariff still needs more valuation for the environment to be implemented compared to the fixed tariff. However, the gap between them has tightened relative to the monopoly and the fringe case. That can be seen from the minimum γ values that generates positive fringe output: $\gamma = 1.31$ for the premium and $\gamma = 0.58$ for the fixed tariff.

In conclusion, it can be claimed that, for a competitive electricity market, premium tariff does not significantly underperform than the fixed tariff in a static duopoly and the fringe equilibrium. Moreover, premium tariff is expected to adjust the changes in the market more rapidly than even a carefully adjusted fixed tariff, since it changes with the market price.

4.3 Fixed and premium tariffs, 3 firms Cournot Oligopoly and the fringe Case

Figure 7 shows how the price, optimal fixed tariff, and quantities at the equilibrium change in response to a change in γ.

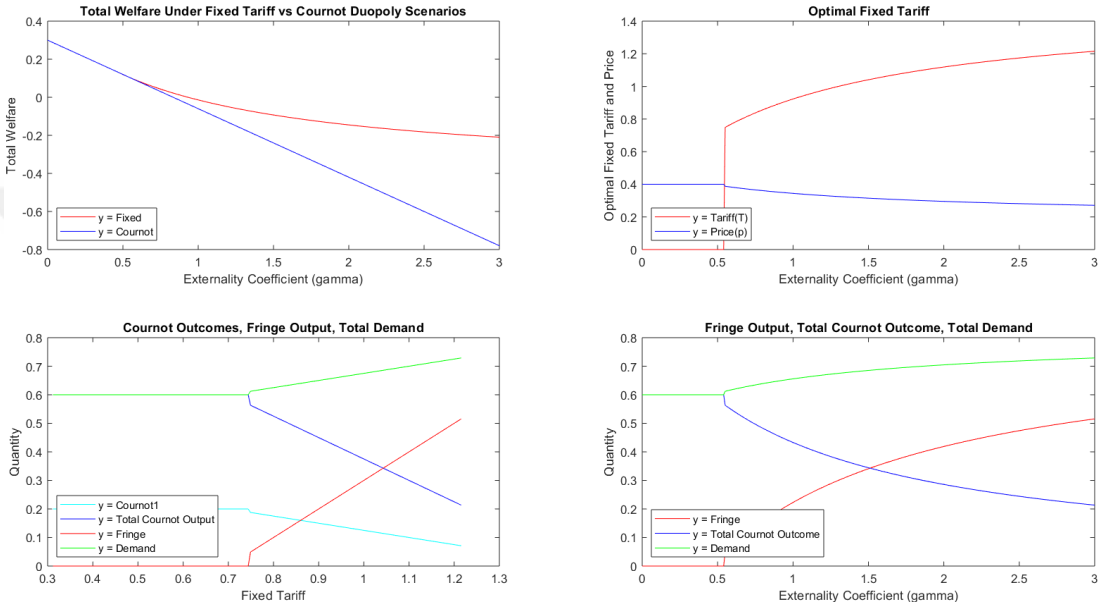


Figure 7. Fixed tariff, 3 firms Cournot oligopoly and the fringe

Figure 8 shows how the price, optimal premium tariff, and quantities at the equilibrium change in response to a change in γ. As it is expected, as number of dominant firms increased to 3 from 2, in other words as the concentration level decreased, the difference between social welfares reached by fixed and premium tariffs decreased and the two policies now resemble each other more. Still there is more fringe output under the premium tariff, and a higher lower bound of γ is needed to lead positive fringe outputs compared to fixed tariff, however the differences in these measures have decreased as well.

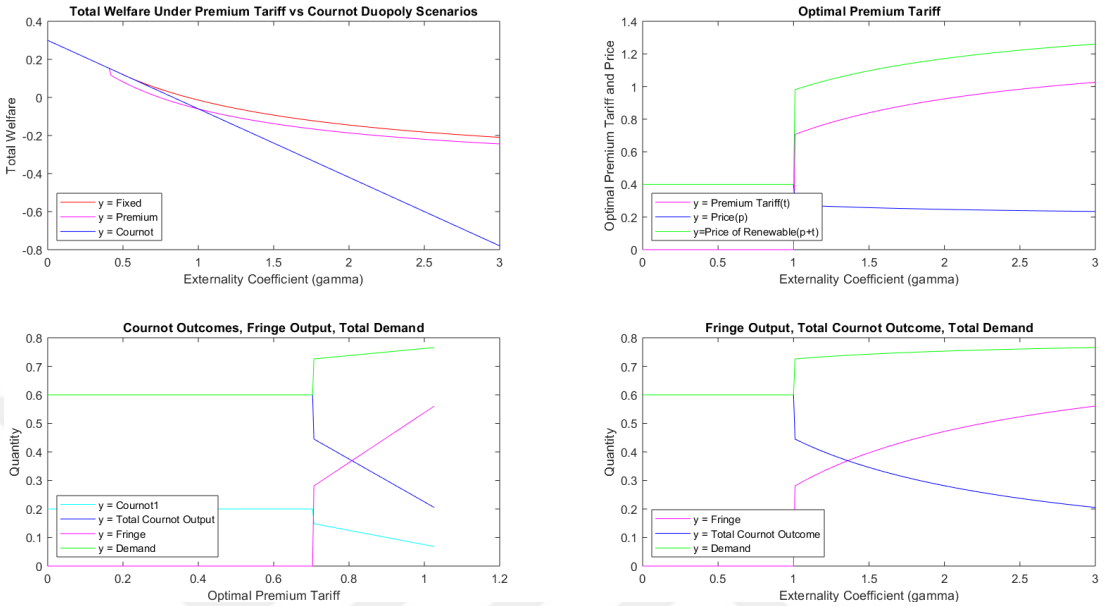


Figure 8. Premium tariff, 3 firms Cournot oligopoly and the fringe

4.4 History of the Turkish electricity market and the current situation

In 2001, the Turkish electricity market structure has started to be liberalized by the Electricity Market Act numbered 4628 (EMA). Throughout the process till 2009, market operations are buffered in case of shortages or surpluses, with balancing mechanisms controlled by TEİAŞ (Turkish Electric Transmission Corporation). In 2009, settlement mechanism for each hour, and a day-ahead planning mechanism are structured, with its final form as a day-ahead market opened in 2011. In 2013, EPİAŞ (Turkish Energy Exchange) is opened which is given the responsibility of organizing the settlement between sellers and buyers, and the day-ahead market mechanisms. In 2015, the intraday market is opened under control of EPİAŞ. Now there are three markets in the wholesale trade sector of electricity: day-ahead market, intraday market, and balancing power market whose former two are operated by EPİAŞ, and the last one is by TEİAŞ.

Among the day-ahead and intraday markets, most of the transactions are realized in the day-ahead market, those who could not buy or sell in this market, make offers in the intraday market. The intraday market works as a normal spot market which can be represented as a discriminatory auction of hourly periods in which suppliers wait for the bids in each period, and then sell the bulk power at the best price they get. However, the operation of the day-ahead market is more complicated, with a PTF (market barter price) set according to the intersection of supply and demand offers, as an hourly market price. Producers, traders, and buyers enter their bids to sell or buy a specific amount from a specific price into the system, and an algorithm sets an hourly price by maximizing the total welfare of all buyers and sellers in that period. Those sellers whose bids exceed the PTF can have an option not to sell from that price, however, if their bids are close to the PTF and compensating them for their loss is found feasible by the algorithm, then they can also be compensated. Those who bid to sell at a cheaper price than PTF get a surplus. The same logic applies to buyers. Besides these markets, sellers and buyers of wholesale electricity can make long-term bilateral agreements which prevents price uncertainties.

The price-setting mechanism in the retail electricity market is a little bit complicated, differing for consumer types: free and non-free consumers. To be a free consumer one's energy consumption needs to exceed the free consumption limit, currently 2000 kWh annually. In that case, he/she can buy from any seller in his/her region, or beyond. Otherwise, the price he/she will buy from is regulated by EPDK (Energy Market Regulatory Authority). The regulated price includes distribution fees (also compensating for transmission fees and the losses and leaks), charge for energy production, responsible distribution firms' profit, and taxes. Therefore, a non-free consumer pays the producer's share, transmission fees, distributor's share, and taxes

(VAT, municipality's share, official television's share, ministry of energy's share for R&D) all reflected in the bill. Free consumers can choose any seller distributing to their region. In the figure 9 below, the change in the free-consumers' consumption volume for the year 2019-2020 is shown.

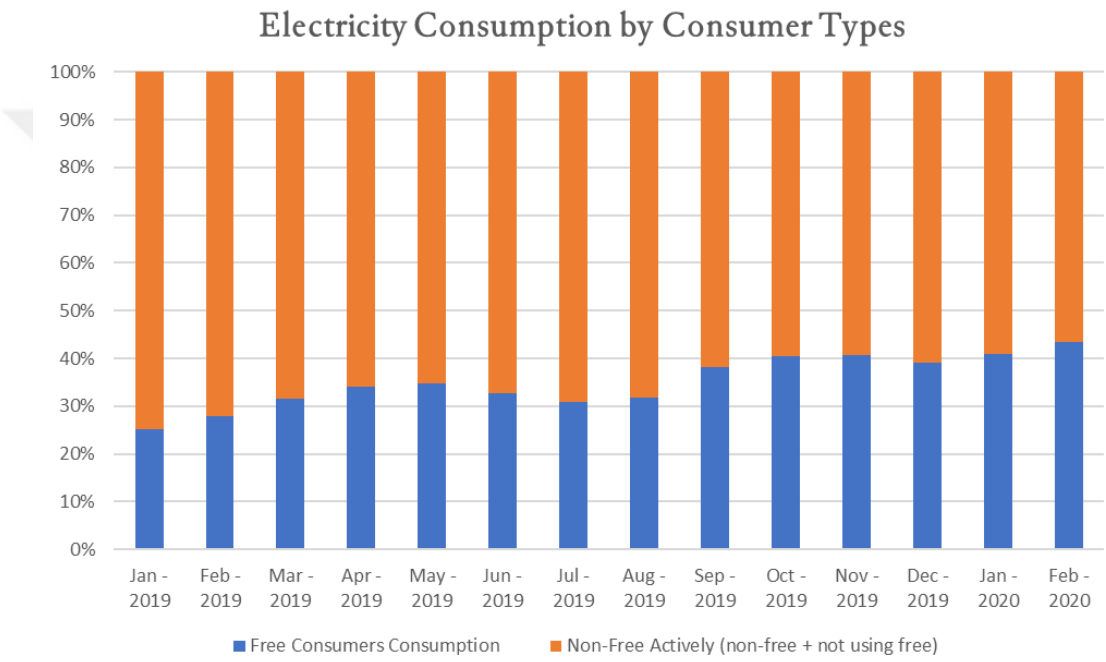


Figure 9. Electricity consumption by consumer types

Source: seffaflik.epias.com.tr

Figure 9 shows that there is an increasing trend in free consumers' share of total consumption, mainly because of the increasing number of free consumers. That is due to two reasons: firstly the free consumption limit has been repeatedly decreased for a few years, such as it was 2000 kWh annually in 2018, 1600 kWh in 2019, and 1400 kWh currently in 2020. By doing that, the policymakers intend to increase competition in the retail sector. Secondly, more people become interested in moving to free-consumption by time, while they had already the right to choose their

procurement companies. This fact can be inferred from figure 10 below. As for figure 9, the consumer category labeled as non-free actively includes the non-free consumers by their annual consumption below the limit, and can-be free consumers but not choosing to do so.

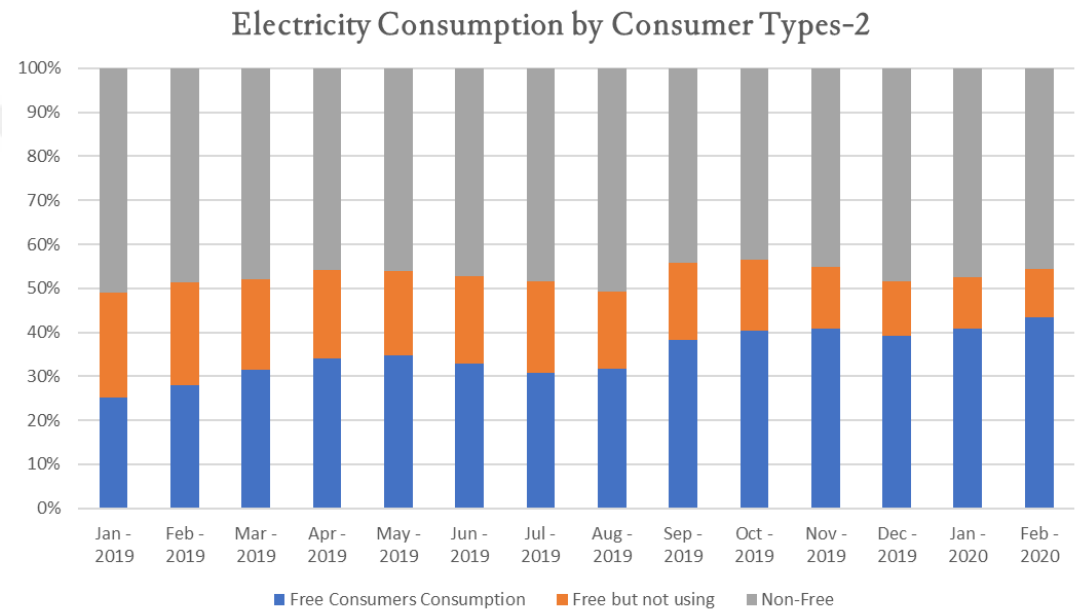


Figure 10. Electricity consumption by consumer types-2

Source: seffaflik.epias.com.tr

With the recent improvements in renewable energy technologies, and the help of the encouragement policies, another option to sell to the system is generated and it is through the responsible distribution firm. Small enough renewable energy generators, which are on the distribution lines, and called distributed generators, sell to the distributor firm at a price set or subsidized by policy-makers. Namely, they sell to the grid through the local distribution firms that they buy energy from if their generation does not cover their electricity needs. Details of the distributed generation

technologies will be explained in the next section. However, to find the approximate amount of DG production in the Turkish electricity market, the license to generate electricity can be used as a proxy. To promote renewable distributed generation deployments, the government issued an exemption from the license payments for generators below a specific limit which is 5 MW currently. Besides, there is a recently added requirement for the exemption which is the generation and the consumption of electricity should be in the same location. Therefore, measuring the unlicensed production is an accurate proxy to overall DG production in Turkey.

It is seen in figure 11 that most of the solar investments are unlicensed which also comprise almost all of the unlicensed investments in Turkey. Therefore, taking solar energy as a proxy for the distributed generation would be reasonable. Remaining important statistics for Turkish electricity markets, especially the amounts of production, both renewable and non-renewable, will be presented in the next sections.

Source	Installed Capacity(Licence - MWh)	Installed Capacity(Unlicen - MWh)	Total(MWh)
Wind	6,549.86	51.97	6,601.83
Rezervoir	6,242.78	0.00	6,242.78
Canal Type	6,046.20	22.22	6,068.42
Sun	174.75	5,872.71	6,047.46
Geothermal	1,404.39	0.00	1,404.39
Biomass	424.87	32.96	457.83
Other	0.00	187.30	187.30
LFG	153.20	0.00	153.20
Biogas	100.93	25.69	126.62
Total	21,096.97	6,192.84	27,289.82

Figure 11. Installed capacities of renewable energy in Turkey by March 2020

Source: seffaflik.epias.com.tr

HHI index measures the concentration in the industry, and it is simply the sum of squares firms' market shares. HHI index varies between 1 to 10000, and below 1000 can be regarded as competitive. Although HHI measure fails to consider the complexities of a specific sector, it can be taken as a starting point in assessing the market power in a given sector. Looking at the figure 12 below, it can be inferred that there is a decrease trend in the concentration for Turkish electricity market.

	HHI Index					
	2014	2015	2016	2017	2018	2019
Generation	1416	1123	673	696	575	550
Installation Capacity	1132	996	873	789	682	599

Figure 12. HHI index for Turkish electricity market

Source: Electricity Market Development Report 2019

4.5 Fixed and premium tariffs, 18 firms Cournot oligopoly and the fringe case

In a market consisting of n firms, each firm's share of output is indicated as s_i, and the Herfindahl-Hirschman Index is measured as: $HHI = \sum_{i=1}^{n} s_i^2$. Current concentration level of Turkish electricity market is around 550 HHI values, as reported by EPDK in 2019 (figure 12). This value coincide with a Cournot oligopoly of 18 firms with homogeneous costs. Since the concept of the fringe is competitive and not-concentrated, I use the HHI value generated by the number of Cournot firms to make approximate comments on the current electricity market environment in the Turkey. Therefore, a case of the Cournot oligopoly of 18 firms, and the fringe is used to simulate a proxy of what Turkish electricity market would look like at least in terms of concentration.

Figure 13 shows how the price, optimal fixed tariff, and quantities at the equilibrium change in response to a change in γ.

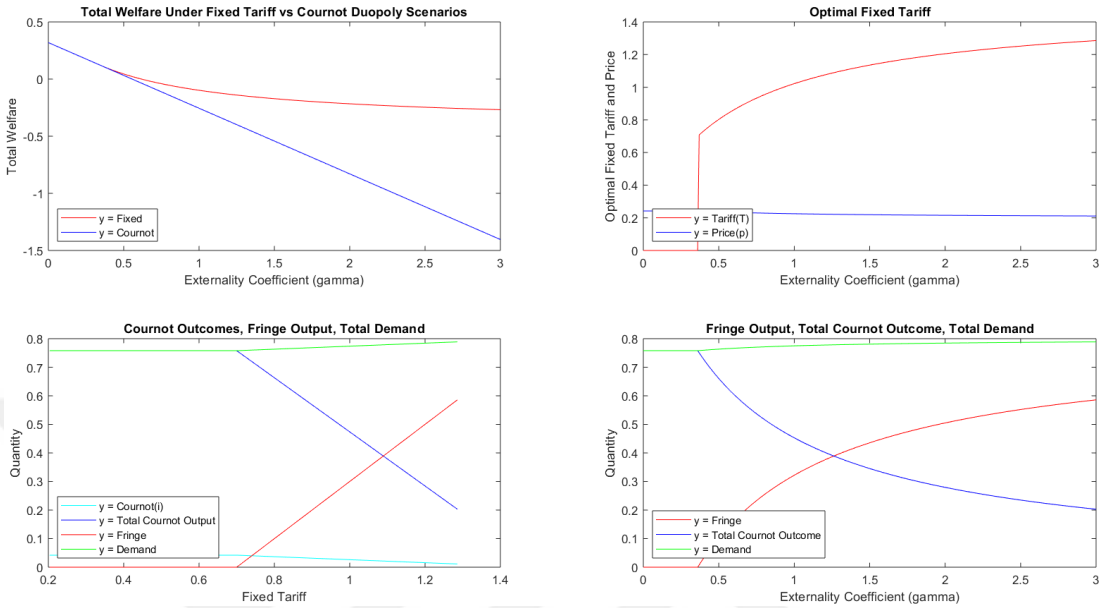


Figure 13. Fixed tariff, 18 firms Cournot oligopoly and the fringe

Figure 14 shows how the price, optimal premium tariff, and quantities at the equilibrium change in response to a change in γ.

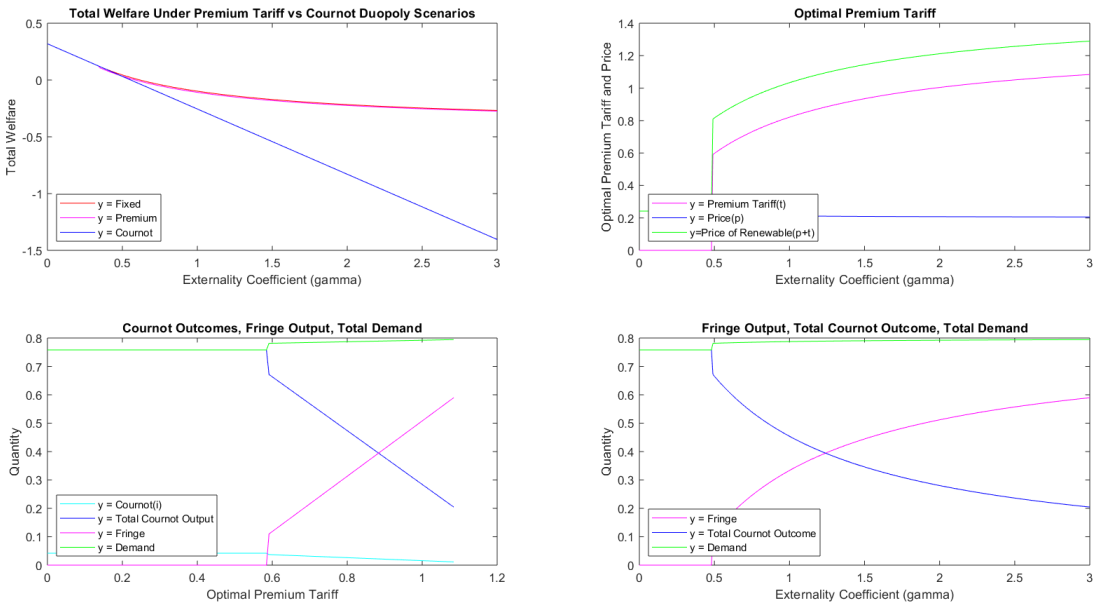


Figure 14. Premium tariff, 18 firms Cournot oligopoly and the fringe

Since the number of firms have been significantly increased compared to the duopoly and the fringe case, the two policies generate nearly same effects on the market. Social welfare generated by the premium tariff is just below the welfare generated by the fixed tariff. The total demand and the renewable fringe output generated by the premium tariff are just above their counterparts generated by the fixed tariff. For the chosen parameter set under this case it can be concluded that, implementing either one of the tools (fixed or premium FiT) does not lead to a significant difference in terms of prices, quantities, and welfare.

CHAPTER 5

CONCLUSION

In the last half-century, electricity markets have experienced two great transformations: deregulation of the generation structure and transition to the renewable generation. Share of the renewable electricity production worldwide has increased to 9.32 in 2018 (figure 1). The reconstruction phase of deregulation similar to the one occurred in UK and US during eighties, has begun to take place in the Turkish electricity market in the last twenty years. Since the process is quite recent compared to those countries, the vast academic literature on the deregulation of the electricity markets can be helpful in the ongoing transformation process. One of the important questions regarding this transformation is the share of renewable electricity generation, both central and distributed, its efficient level, and the optimal policy structure to lead and sustain this generation level.

There is a trade-off between the cost of the transition to a electricity generation portfolio with more renewable generation capacities and the cost of environmental externality caused by non-renewable generation. The latter component of the trade-off is more crucial in terms of leading to irreversible effects on the environment, society, and consequently the economy, while the cost of increasing the renewable generation's share is predictable and short-term. These costs include new infrastructure spendings needed to facilitate distributed renewable generation, higher costs of generating renewable electricity, and the cost of uncertainty and inability of determining the production time, which makes the continuous adjustment between supply and demand more difficult. Representing all of these costs in one model can make the analysis unnecessarily complicated. This research used quadratic and higher

costs of generating renewable electricity compared to non-renewable electricity to represent this trade-off, although it does not have to be the case in the reality. This approach is conceptually justified by (Borenstein 2012) and used by (der Fehr and Ropenus 2017) papers.

This research, in line with (der Fehr and Ropenus 2017), uses the dominant firm and the fringe model and makes a contribution of optimal tariff solutions for the fixed and premium tariff cases. This allows us to make comments on the differences in the outputs, prices and welfares caused by these policies at their optimal levels. Therefore, relying on a theoretical model, I propose a basic framework to evaluate the efficiency of tariff types used to support the renewable electricity generation. Further structural research can provide parameters to make more approximate comments. Since the cost data of the firms is not public, to apply this model exactly on the reality of Turkish electricity market is beyond the scope of this thesis. Accessing to the cost data can facilitate the application as a further project. Therefore, the application of this research is bounded by the current information about Turkish electricity market's concentration reflected in the reported HHI values(figure 12).

In summary, the monopoly and the fringe case shows that the fixed and the premium tariff lead to significantly different outcomes. Under the premium tariff, since the monopoly can effect the fringe's price, $(p + \tau)$, it cuts its price more than it does under the fixed tariff. This leads to the rebound effect: although does not cause higher external costs by increasing the non-renewable output, there is an overproduction of renewable electricity under premium tariff. For environmental reasons this may be claimed as desirable, however in terms of welfare calculations, it leads to welfare losses(figure 4). Premium tariff needs higher γ values to be implemented, meaning that for a government that does not value the environment

much, it is less likely to be implemented compared to the fixed tariff. These features of the premium tariff is especially present if the market is concentrated, namely the monopoly and the fringe case. As the number of firms increase, the market power of the dominant firms becomes weakened. Therefore, the rebound effect they cause decrease, and the two policies resemble each other more as the market becomes less concentrated.

When the Turkish electricity market's generation concentration index is considered (HHI=550, figure 12), it can be said that the market is competitive and not concentrated. The approximate number of firms in the oligopoly to reflect this HHI value is 18. When the 18 Cournot firms and the fringe case is examined, it is seen that the two policies are very similar in terms of the outcome. However, adjusting the true fixed tariff value can be difficult for the decision makers. Moreover, it may not adapt the changes in the market as fast as the premium tariff, even if the fixed tariff is set by using dynamic indexes. This question should be examined in a further research, such as whether a sliding premium or a fixed tariff adjusted using a dynamic index (such as a price index) performs better. Figure 12 shows that HHI was 1416 in 2014, above the competitive market definition. With the information set at hand and the help of this research, it can be said that the transition to a premium tariff for regulating the renewable electricity investments in the Turkish electricity market can be a better idea now, compared to before when the HHI was higher.

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