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Do the High Spectrum Prices Harm Consumers? Evidence from Poland

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Abstract:

Purpose: *This paper contributes to research on potential links between high license fees and wireless markets outcomes. It aims to examine whether high prices paid by mobile service providers in Poland at the 4G spectrum auction could slow down network deployment and hurt Polish mobile consumers.*
Design/Methodology/Approach: *The paper is based on the literature on the spectrum management, public reports published by European Commission (EU), Polish Office of Electronic Communications (UKE) and international diagnostic companies studying the quality of internet. We also study data provided by Ookla® based on John Paul II University in Biała Podlaska analysis of Speedtest Intelligence® data from 2017 to 2020 (Ookla® trademarks used under license and reprinted with permission).*
Findings: *We found no evidence for the statement that the high costs of spectrum have hurt Polish consumers. Our research has revealed that the quality of the Internet in Poland has been steadily improving, and the prices of mobile services are falling. We also found no significant changes in the relationship between Poland's market outcomes to other countries - the quality of the Polish Internet remains high both before and after the auction, and mobile service prices remain among the lowest in the EU for years. Our findings provide thus some support for the veracity of the sunk cost argument in relation to mobile markets.*
Practical Implications: *The discussions made in this paper could help policy makers in Poland and other countries in spectum management decisions.*
Originality/Value: *This is the only article that analyzes market outcomes in the Polish mobile market in the light of LTE spectrum action in Poland.*

Keywords: *Spectrum auction, license fee, spectrum management, sunk cost, mobile Internet market.*

JEL: *D44, L51, L96.*

Paper type: *Research article.*

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1. Introduction

The telecommunications industry is essential for the development of modern economies. Mobile technologies intensify the productivity of existing industries and stimulate the creation of new services and business models, contributing to global economic growth. In 2021, nearly 5% of the global GDP came from the mobile industry. The global mobile ecosystem supported 26 million jobs and generated nearly USD 500 billion in taxes significantly reinforcing public finances (GSMA, 2022).

Apart from the economy, there is also a huge impact of mobile technologies on society. They provide connectivity between people around the world, connect citizens with services and workplaces, support efforts to improve access to information, medical care and education contributing to a better quality of life. Radio-based technologies play also a key role in eliminating social barriers, levelling socio-economic inequalities between regions and helping to achieve the Sustainable Development Goals (GSMA, 2021; ITU, 2019). Of great importance, especially nowadays, is their contribution to public safety and national defence.

The key input of mobile services is radio spectrum. It constitutes a scarce and limited national asset. Unlike other natural resources, spectrum cannot be depleted, however, due to the specific physical properties of radio waves, it is easy to be interfered with, so optimal spectrum management requires coordinated efforts (ITU-R, 2014; Bauer, 2001).

In the early stages of wireless technology development spectrum was allocated without explicit fee in "beauty contests" on a "first come, first served" basis and sometimes even by lotteries. However, this approach resulted in many inefficiencies, prompting governments and regulators to adjust their policies to new market conditions (Bauer, 2001; 2003). Technological developments have enabled many new spectrum applications, resulting in a significant increase in the demand for this limited asset. Spectrum became a scarce resource - so new market-based approach to spectrum licensing started to be needed. Common way of spectrum allocation became auctions.

Despite the general acceptance of license fees, there has been a long debate about the potential negative impact of high license fees on the growth of wireles market. There are two opposing views in this discussion. Standard economic theory believes that license fees are sunk costs so they do not influence the subsequent evolution of mobile market, in particular don`t affect pricing and investment decisions.

At the same time, some researchers and industry representatives point out some weaknesses in the sunk cost argument in relation to mobile markets claiming that high sums paid by carriers could have a negative impact on retail prices, investment decisions and they could slow down network deployment.

This paper contributes to research on potential links between high license fees and wireless market outcomes. It aims to examine whether high prices paid by mobile service providers in Poland at the 4G spectrum auction could slow down network deployment and hurt consumers.

Our analysis showed that both economic theory and previous empirical studies do not give conclusive findings regarding the effects of high spectrum fees on consumers. Studies of specific markets, especially markets such as Poland, where high spectrum prices have been paid can therefore provide additional evidence and shed some light on the applicability of the sunk cost argument to the mobile markets contributing to a better understanding of this issue and providing valuable information that can help policymakers in spectrum management decisions.

We use public documents and EU reports, as well as data provided by international diagnostic companies studying the quality of internet, and look at market outcomes (price and quality of mobile services) before and after the Polish LTE auction to find whether there is any evidence that high spectrum prices have hurt consumers. To better capture the potential impact of high license fees on the Polish mobile market, we contrasted Poland's outcomes with those of other countries and examined whether there were any distortions in this relation.

The substantial changes in Poland's position compared to other countries after the 4G auction may provide some support for the theory that high spectrum prices have a negative impact on the mobile market in Poland.

We found no evidence for the statement that the high costs of spectrum have hurt Polish consumers. Our research has revealed that the quality of the Internet in Poland has been steadily improving, and the prices of mobile services are falling. We also found no significant changes in the relationship between Poland's market outcomes to other countries - the quality of the Polish Internet remains high both before and after the auction, and mobile service prices remain among the lowest in the EU for years.

The article is organized as follows: the next Section includes a theoretical discussion on the potential impact of license fees on the development of the mobile Internet market (particularly on prices and quality of services). In Section 3, we juxtapose theory and practice by presenting an overview of related empirical and experimental studies. Section 4 contains a case study of the Polish telecommunications market.

In this section, we analyse mobile consumer outcomes before and after 4G auction to find whether there is some evidence that the high spectrum prices in Poland harmed Polish consumers (translated into higher service prices and worse quality of mobile services). In section 5, we summarize our findings.

2. Conceptual Background

There has been a long discussion in the literature on the potential impact of license fees on mobile market outcomes, in particular on mobile prices and quality of service (level of network investment). Opinions in this discussion are divided. Some telecommunications industry researchers support the thesis that high spectrum prices don`t hurt consumers and do not have negative effects on the growth of the telecommunications market.

In their opinion, license fees are a sunk cost, i.e., a cost that was incurred in the past and cannot be recovered. According to the classical theory of microeconomics, optimal choices should be based only on variable revenues and costs (firms should set prices at a level where marginal revenue equals marginal cost). Since sunk costs are a category of irrecoverable fixed costs, which do not change as a result of the choices made, they should not be taken into account when making management decisions.

In particular, sunk costs should have no effect on pricing and investment and shouldn`t influence market exit decisions. The company should stay in business as long as revenue covers variable costs, regardless of sunk costs (Garrison *et al.,* 2010; Kwerel, 2000; Buchheit and Feltovich, 2011). The above argumentation, especially the inability to recover sunk costs, supports the idea that the prices paid by operators should not be passed on to consumers.

Despite these theoretical explanations some researchers and representatives of industry organizations expressed concerns about application of the sunk cost argument in the context of mobile markets and reported that high license fees could have a negative impact on the growth of mobile market, in particular on the operators' revenue and investments (ITU, 2012; GSMA, 2019).

These doubts are also supported by the results of recent studies in financial and behavioral economics. New research reveals that the view derived from classical economic theory does not properly describe how firms actually make pricing decisions. In reality, companies often price their products using cost-based methodology, which instead of marginal cost that is often difficult to estimate, takes into account the average total cost. According to this concept, higher sunk costs mean higher fixed costs and thus higher prices (Buchheit and Feltovich, 2011**;** Horngren *et al.,* 1997).

Nobel Prize winner, behavioral economist Richard Thaler points out that relying solely on normative theory to predict the market participants` behavior can lead to systematic errors because in certain "well-defined situations" many consumers behave in a way that is in opposition to economic theory (Thaler, 1980). He defined the phenomenon called the sunk cost fallacy, which consist in the fact that entities, against to the theoretical economic beliefs do not ignore sunk costs when making

decisions - on the contrary, after investing resources they continue their activities willing to recover the incurred expenditures. One explanation for this phenomenon is a syndrome called loss aversion. Entities covered by this syndrome find it difficult to accept the fact that the sunk cost has been lost and they follow through on endeavor whether or not the current costs exceed the benefits.

Sunk costs fallacy could be observed not only in managers` or investors` decisions, but it can also occur in many other areas, including government decisions regarding the continuation of military conflicts, the functioning of start-ups or maintaining personal relationships. There is also evidence of similar behavior inconsistent with rational economic choices during spectrum auctions (French, 2008; Moss, 2021).

In turn, Bauer (2003) noted that the classical sunk costs argument is valid under strict assumptions regarding the mobile market competition or working of capital markets. If these assumptions are relaxed to better reflect the characteristics of the mobile industry, license fees may have an impact on the evolution of the mobile sector. One such assumption is considering spectrum licensing as a one-time game, in which interactions between market participants at different stages of development do not depend on each other.

Such a classical approach ignores the fact that investments in the network have a recurring nature, and therefore high license fees reduce returns on the network investments already made. In the long perspective, companies will adjust their investment strategies reducing their expectations of future returns on investments which in turn may lead to a decrease in network investments. The inability to obtain sufficient returns may even lead to withdrawal from the market or consolidation, which is referred to in the literature as a hold-up problem (Marsden *et al.*, 2017; D'Ostuni and Tremolada, 2021).

Another weakness in the traditional sunk cost model is that it ignores the failures of capital markets and financial constraints that telecoms often face, especially in European markets (Cave and Solomon, 2019). It implicitly assumes that companies use internal financing, which plays an essential role in investment decisions (Lewellen and Lewellen, 2016). In case of debt finance, results from standard theory need not apply. Operators who are forced to finance high license fees with debt face higher costs of capital.

An increase in debt negatively affects credit ratings, which can lead to higher credit rates or the need to increase credit insurance. Additionally, according to the pecking order theory, the cost of financing increases as information asymmetry increases. External investors have less information about planned investments and the financial condition of the company, so they may require greater risk compensation, which leads to an increase in the cost of external capital and deepens financial constraints (Marsden *et al.*, 2017).

High cost of capital associated with external financing may also reduce the profitability of some investments and consequently could lead to de-escalation, i.e. redirection of capital to markets with higher expected profitability and thus limiting the level of investment in markets with high spectrum costs (McAffe *et al.,* 2010).

Considering financial constraints, high spectrum prices may also have negative implications for the structure of competition. Operators with greater budget constraints will be forced to rely on more expensive external financing, which could further deepen differences in their profitability and distort competition (Cave and Solomon, 2021).

Kwon *et al.* (2010) noted that the license fee payment method is an important factor affecting market outcomes. Their theoretical analysis show that the use of royalties instead of the commonly used upfront fees can increase the supply of spectrum and enhance incentives for network investment. Hovever, in the context of consumer prices and economic efficiency, the most favorable method is the profit-sharing payment.

Taking into account the long-term perspective of the licensing process makes also possible scenarios where the positive effects of high license fees are workable. After investing in spectrum firms can have an incentive to increase market share and raise revenue by reducing service prices. Similarly, if the license fees do not result in serious financial constraints, telecoms have the motivation to rapidly develop their networks and improve the quality of services offered in order to get new subscribers and increase future revenues (Bauer, 2003).

3. Review of Empirical and Experimental Studies

The theoretical discussion presented in the previous section revealed that the sunk cost argument in the context of wireless markets is not uncontested and the implications of license fees for downstream markets are ambiguous and context-dependent. In this chapter, we will try to juxtapose theory and practice by reviewing related empirical and experimental studies.

Such studies have been conducted for more than two decades. They were intensified after a series of European 3G auctions, when in some countries telecoms paid for spectrum amounts that far exceeded expectations, which raised concerns about the negative effects of high license fees (Bauer, 2001).

Empirical studies mainly look at relationship between various spectrum management policy choices (e.g., spectrum availability, spectrum allocation method) and the level of social welfare and development of mobile market. Of particular interest is examining whether and how spectrum costs translate into consumer outcomes, especially mobile prices and quality of wireless service.

One of the first sunk costs-related studies were conducted by Kwerel (2000). He used data from the 30 largest U.S. cellular telephone markets between 1985 and 1998 to examine whether license fees increase the price of wireless services. He found that the average price of services 3 years after the sale of usage rights was 12% lower than the average price 3 years before license sale.

Moreover, the prices set by operators who purchased licenses were no higher than those set by companies that obtained them for free. Thus, the results of these studies show that paying for a license does not lead to higher prices for consumers and provide support for the classic sunk cost argument discussed in Section 2.

Bauer's study (2003) was based on data on 18 2G mobile service providers from 18 OECD countries and was conducted separately for two groups of customers, residential and business. First, he tested a simple bivariate correlation between license fees and mobile service prices. Then multivariate econometric models were estimated, which took into account many additional variables shaping the prices of wireless services such as GDP, prices and availability of substitute (fixed) services, population density and the national wage index. The research did not reveal significant relationships between license fees and mobile service prices neither for residential nor business customers.

Admittedly, the model parameter estimates indicated a positive correlation between license fees and prices for the residential customer and a negative correlation for the business market, but these relationships were not statistically significant. The only significant determinants of prices for residential consumers turned out to be the cost of fixed voice service and market competition.

Using data from 21 OECD countries which awarded 3G spectrum Park, Lee and Choi (2010) examined how licenses cost and the method of spectrum licensing affect the telecommunications market (consumer prices, timing of new services and market structure). In addition, they investigated whether license fees delayed investment and the timing of 3G service launch and if they affect market structure by increasing concentration.

The authors found no evidence to support the negative effects of high license fees. Neither license fees nor the use of auctions to allocate spectrum resulted in higher service prices or investment constraints. The use of auctions had also no effect on increased market concentration. The only statistically significant determinants of service prices turned out to be variables describing the size of the market (higher consumer prices were recorded in countries with lower GDP).

The analysis of the links between spectrum prices and the level of network investment was also conducted by NERA Economic Consulting (2017). They focused on 4G services and based their studies on spectrum awards taking place between 2008 and 2016. To avoid distortions resulting from differences in ability to

pay, three separate analyses were conducted for countries with different levels of income. To assess investment, due to the difficulty of compiling comparable data, an aggregate indicator measuring service quality and 4G uptake was used. The study revealed that countries with lower spectrum costs have lower consumer prices and better wireless outcomes. It was also estimated that high spectrum prices resulted in welfare losses for consumers with purchasing power of about USD 250 billion.

A study conducted by LStelcom, VVA and Policy Tracker (2016) on behalf of the European Commission (EC) based on the results of spectrum awards in EU fund that member countries in which operators paid higher amounts for spectrum faced worse 4G network availability. Their research included also the feedback from MNO stakeholders which revealed that delays in network development are largely affected by investment constrainsts resulting from high spectrum costs.

Hazlett and Munoz (2009) highlighted that spectrum allocation practices focused on increasing government revenues, e.g., by limiting the amount of spectrum available to consumers, have negative effects on social welfare and the development of wireless markets. Based on wireless telephony services from 29 countries, they found that service prices (measured by telecoms revenue) decrease with greater competitive market structures and the amount of available spectrum.

Using data from mobile carriers operating in 24 countries between 2005 and 2014, Cambini and Garelli (2017) empirically analyzed the determinants of mobile industry revenues, considering them as a proxy for service prices. Among the factors analysed, in addition to license fees, there was also the amount of available spectrum, but the results they obtained were different from Hazlett and Munoz (2009) findings. It may have been partly due to the methodology used.

Cambini and Garelli noticed potential endogeneity between some regressors and used a special dynamic model based on the Arellono and Bond (1991) estimator, which gives better results in case of endogeneity and reverse causality. After including potential endogeneity, they found that spectrum availability and license fees have no significant impact on mobile operators' revenues. Their findings thus support the theoretical prediction that license fees are a sunk cost and are not passed on to consumers in the form of higher prices.

A recent study of Bahia and Castells (2022) also considers the problem of dual causality between spectrum costs and downstream prices. They reviewed data on 229 mobile operators from 64 countries (34 developed and 30 developing) operated between 2010 and 2017 to investigate the impact of various spectrum management policies on mobile market outcomes.

Authors applied a special methodology which allowed them to isolate the impact of spectrum fees among other factors shaping mobile service prices. To do so, they used explanatory variables that affect spectrum prices, but do not affect consumer

outcomes and also applied CPR metric defining the price of spectrum as a proportion of revenue, which allows considering the relative cost of spectrum from the operator's perspective and gives some insight into profitability of spectrum fees as an investment.

Controlling a two-way effect between 4G spectrum prices and consumer outcomes, authors found evidence of a causal relationship between high spectrum fees and negative consumer outcomes. In both developed and developing countries, high spectrum prices have contributed to slower network deployment and lower overall network quality.

In addition, they found that the amount of spectrum available and the timing of its allocation also have a significant impact on network coverage and quality of services. The research revealed additionally some evidence of a negative impact of spectrum fees on service prices in developing countries, but the results were not statistically significant.

Offerman and Potters (2006) in their experimental studies found that in a Bertrand-type duopoly fees paid to get the right to operate in a market resulted in high prices for consumers regardless of a form of entry fee (fixed fee or fee determined through an action). Authors also pointed out that such relations may have resulted from using a mark-up pricing rule and do not apply in the monopoly treatment.

The experiment conducted by Buchheit and Feltovich (2011) revealed that contrary to standard microeconomic theory, the way prices were set varied with the level of sunk costs. The relationship between the level of sunk cost and consumer price followed a U-shaped pattern: at low levels, increasing the sunk cost resulted in lower average prices, but at higher levels, increasing the sunk cost resulted in high average prices. Authors pointed out that the possible explanation for this relationship may be the loss aversion (section 2).

4. The Case of Polish Mobile Market

In this section, we will present a case study of the Polish telecommunications market. The first and so far only spectrum auction in Poland took place in 2015 and ended with very high revenue compared to other countries, which may have raised concerns about the negative impact of high license fees on the downstream market.

To see if high license fees in Poland have translated into a deterioration in the Polish mobile market we will examine the evaluation of basic consumer outcomes such as prices, availability and quality of service between 2014-2020 i.e. before and after the 4G auction.

The lower limit of the time frame is due to data availability: we could not find previous consistent data on the quality and prices of mobile internet. We limited the

research period to 2020, as mobile services in many countries since then have been provided with 5G technology on the basis of dedicated 5G bands, especially C-band, which was imposed on all Member States by the European Electronic Communications Code to distribute by the end of 2020 (European Parliament and Council of the EU, 2018). A significant number of Member States have complied with this obligation, as according to the EC, more than 50% of the available C-band spectrum had been allocated by the end of 2020 (EC, 2020).

In Poland, however, 5G spectrum has not yet been distributed which may be one of the important reasons for the discrepancies in the quality of mobile services in Poland and the world, and may wrongly suggest that the diminishing quality of mobile services in Poland compared to other countries resulted from high 4G spectrum prices.

Due to the development of technology, the quality of the Internet in the world is naturally improving, and the prices of mobile services are following a downward trend. In order to reduce the weight of global trends and better capture the potential impact of high license fees on the Polish mobile market, we benchmarked the Polish results with those of other countries and investigated whether there are any distortions in this relation.

The visible changes in position of Poland compared to other countries after the 4G auction could provide some support for the theory that high spectrum prices have had a negative impact on mobile market in Poland.

4.1 Structure of Mobile Internet Market in Poland

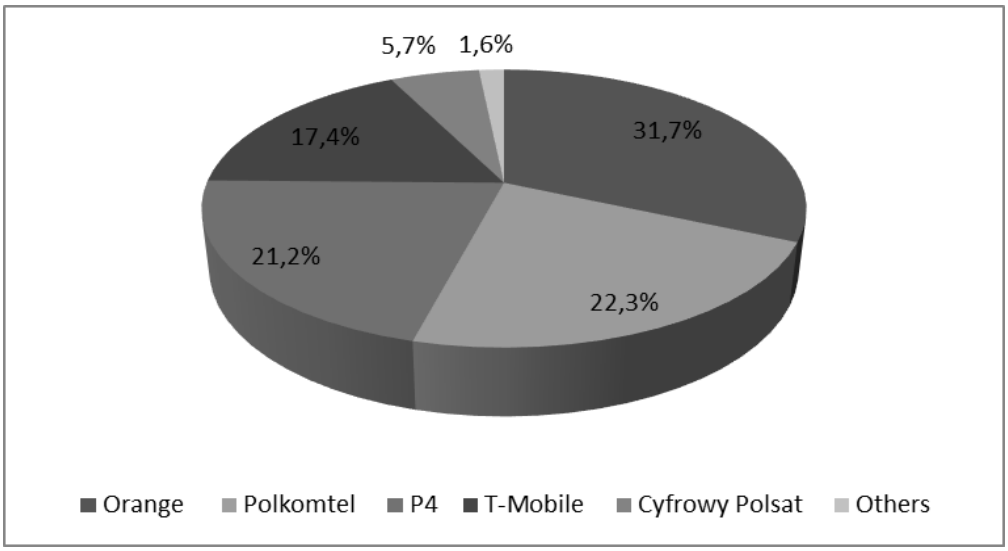
The Polish mobile Internet market has been dominated for years by 4 major operators Orange, Polkomtel (Plus), P4 (Play) and T-Mobile. These providers operate on the basis of their own infrastructure as mobile network operators (MNO) and together occupy almost 93% of the market (Figure 1).

Until recently, there was another MNO in the Polish market - Aero 2, but it was overtaken by Polkomtel in late 2021. Orange has been the leader in terms of market share - in 2021, its share of the total number of users was almost 32%.

The runner-up was Polkomtel, which due to the Aero 2 takeover served more than 22% of users. The market shares of P4 and T-Mobile are 21.2% and 17.4% respectively. In addition to the four MNOs, mobile services in Poland are provided by mobile virtual network operators (MVNOs).

One of them is Cyfrowy Polsat which belongs to the same capital group as Plus and has the largest among all MVNOs share of the total number of users (5.7%).

Figure 1. *Operators` shares in terms of the number of mobile Internet subscribers in Poland in 2021*



Source: *Based on the data published by the Office of Electronic Communications (UKE, 2022).*

The growth of the mobile services market in Poland is of particular importance. It is due to the low level of fixed-line Internet development - in 2021, the penetration rate of fixed Internet services in Poland was the lowest among all EU Member States, at only 22.4% (UKE, 2022).

Due to deficiencies in fixed Internet infrastructure, mobile Internet in Poland is a substitute for fixed lines and for many consumers is the only way to access the network. In this context, it is important for Polish consumers to efficiently and timely allocate the radio frequencies necessary for the provisons of mobile services.

4.2 Polish LTE Auction

The Polish LTE auction was the first-ever auction of radio spectrum in the Polish telecommunications market. It offered frequencies necessary to provide mobile services in LTE technology. There were 5 blocks (2x5 MHz) in the 800 MHz band and 14 blocks (2x5 MHz) in the 2.6 GHz band available in this auction. In view of the shortcomings in the fixed Internet infrastructure, the LTE auction represented an opportunity for Poland to meet the goals of the European Digital Agenda, which was to provide high-speed broadband to all Europeans by 2020 (EC, 2010).

Six entities participated in Polish spectrum auction: four MNOs (i.e. Orange, P4, T-Mobile and Polkomtel) and two other players: NetNet and Hubb Investment. The bidding process took place under the rules of simultaneous multiple-round ascending bid auction (SMRA) - an auction format commonly used in other countries.

However, the Polish regulator applied some special rules that distorted the bidding process and made the course of the Polish auction different from other such auctions around the world. The lack of credibility of the bidding and inability to enforce the bids made by auction participants provided an incentive for speculative bidding.

Additionally, the auction rules did not allow for controlling the pace of the auction and, if necessary, bringing it to a faster conclusion. This led to a long bidding process that could not be stopped with the existing rules (Kuś, 2020). In order to prevent economic losses connected with delays in spectrum assignment, the Polish government decided to make a controversial and unusual change in auction rules by establishing a final round of sealed bids on the 116th auction day. These changes were criticised and became the source of much opposition from operators and market observers.

The final round of sealed bids (round 513) took place on October 15, 2015. Spectrum was sold to five players (one of the participants, Hubb Investments, dropped out of the bidding early in the auction). Three players, Orange, P4 and T-Mobile, got spectrum in both bands. Polkomtel acquired only 4 blocks in the 2.6 GHz band while NetNet acquired 1 block in the 800 MHz band. While the changes in auction rules helped to close the auction, they enhanced the incentives for strategic bidding in the final phase of the auction and increased the risk of inefficient allocation of spectrum and unsold licenses (Kuś 2021).

Fortunately, the darkest scenario did not come true. Although one of the players (NetNet) who offered the highest price for a single block dropped the winning license, the second highest bidder (T-Mobile) agreed to take it and finally all the available spectrum was sold.

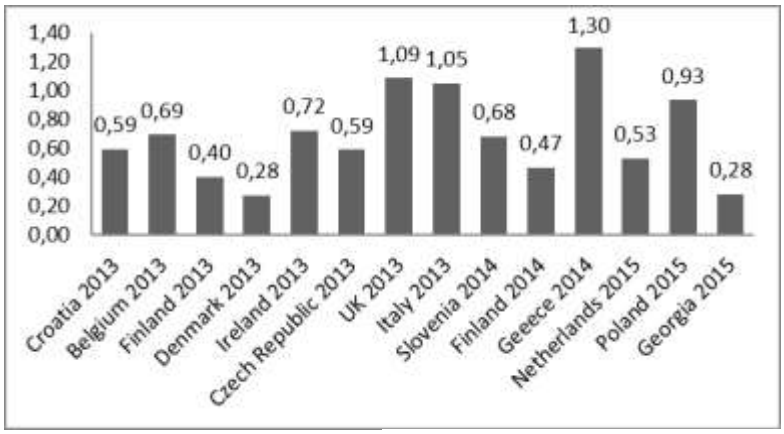
The total revenue from the auction was over PLN 9 billion and was among the highest in Europe. High prices were recorded especially in particularly significant for telecoms 800 MHz band, where they reached $0.93/MHz/Pop (Figure 2).

The high prices paid by mobile operators in Poland have raised concerns about the potential negative effects on mobile market and consumers. In the next section, we will examine if there is some evidence that the high spectrum prices have translated into the quality and cost of mobile services.

4.3 Consumer Outcomes in Polish Mobile Internet Market

In this sestion we will examine the evolution of basic consumer outcomes such as prices, availability and quality of services in the Polish mobile Internet market between 2014-2020 and analyse how the Polish mobile outcomes fare against other countries. Comparing Poland to global trends will help us to examine whether the high prices paid for 4G spectrum in Poland translated into a deterioration in the Polish mobile market.

Figure 2. *Spectrum prices for the 800 MHz band [in $/MHz/Pop] for European auctions between 2013-2015*



Source: *Based on PolicyTracker data: https://www.policytracker.com/Bands/800-mhz-pricing/.*

4.3.1 Prices of mobile Internet services

Analyzing the prices of mobile services raises some difficulties due to the wide variation in the tariffs offered by individual operators and their evaluation over time as a consequence of the increase in demand for mobile data. Thus, some researchers, especially in more complex international studies, use average revenue per user (ARPU) as a proxy of downstream prices. This measure, however, does not reflect exactly the actual prices paid since its value is affected by the amount of data consumed by users.

Thus, a similar ARPU can be observed in case of a large number of low-cost services as well as in countries with low usage of expensive services.

In this paper, prices are measured by the cost of 1GB data transfer. We used data published by the Polish regulator - the Office of Electronic Communications (UKE) in periodical reports relating to the level of mobile Internet prices in Poland. To achieve insight into the pricing of mobile services before and after the Polish LTE auction, we will focus on the data from 3 available reports covering the period 2014-2020.

The minimum, maximum and average values of the cost of 1 GB of data transfer offered by mobile operators in Poland are shown in Table 1 (the data does not include Aero 2, which offered mainly free Internet access service).

The data in Table 1 shows that unit prices varied widely between operators, especially in 2014 when customers for 1GB of data paid from PLN 0.66 (Play) to PLN 19.12 (T-Mobile). In 2018 and 2020, the difference between the cheapest and most expensive price of 1 GB was much smaller, PLN 2 and PLN 1.86, respectively.

Looking at a price evaluation over time we can see that mobile prices in Poland dropped significantly. Particularly large price declines were recorded between 2014 and 2018, average unit prices were lower from 55% (Play) to as much as 87% (T-Mobile).

Table 1. *Minimum, maximum and average costs of 1 GB of mobile data transfer (in PLN) offered by individual operators in Poland between 2014-2020*

Operator	Measure	2014	2018	2020	Percentage variation of average cost	
					2018/2014	2020/2018
Cyfrowy Polsat	Minimum	2.05	0.87	0.72	-76%	-4%
	Average	**4.04**	**0.97**	**0.93**		
	Maksimum	16.55	1.10	1.14		
Orange	Minimum	2.04	0.2	0.29	-77%	-6%
	Average	**5.23**	**1.19**	**1.12**		
	Maksimum	10.80	2.08	2.08		
Play	Minimum	0.66	0.62	0.22	-55%	-26%
	Average	**1.55**	**0.70**	**0.52**		
	Maksimum	2.85	0.83	0.95		
Plus	Minimum	2.31	0.89	0.75	-63%	-4%
	Average	**2.71**	**1.01**	**0.97**		
	Maksimum	3.85	1.16	1.21		
T-Mobile	Minimum	1.46	0.08	0.24	-87%	-16%
	Average	**5.33**	**0.67**	**0.56**		
	Maksimum	19.12	1.08	0.98		

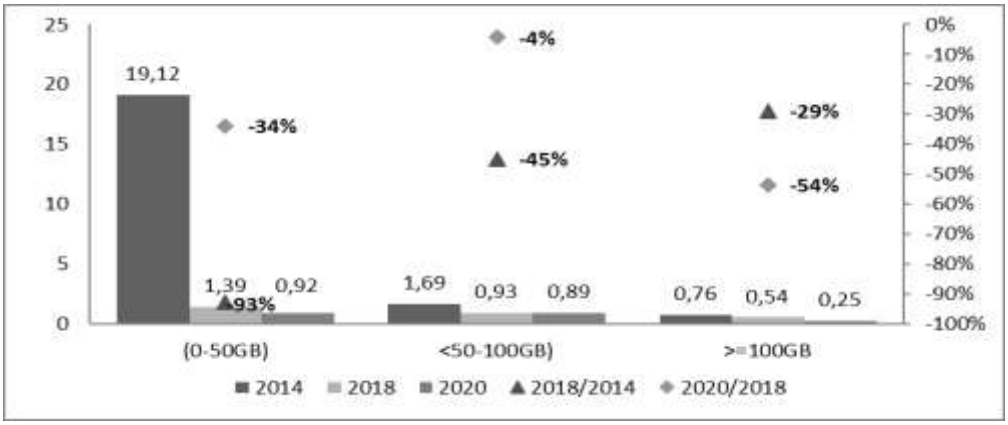
Source: *Own elaboration based on the Office of Electronic Communications reports (UKE, 2014, 2018, 2020).*

Analyzing prices by different data limits also supports the decreasing price trend (Figure 3). In each data transfer category prices fell over the 2014-2020 period. The largest decrease was recorded for services with transfers category up to 50GB, where the unit price in 2018 was 93% lower than 4 years earlier.

In 2020, the largest price drop of 54% was noticed for services with at least 100GB data limit. In other transfer ranges, prices in 2020 also fell by 34% for the limit up to 50GB and by 4% for the range from 50GB to 100GB. We can also observe economies of scale - the actual per unit cost of data was lower in offers for higher usage profiles.

To compare the mobile prices in Poland against the EU, we used the EU reports published annually since 2015 as a part of activities related to A Digital Single Market Strategy for Europe (EC, 2015). These reports provide comprehensive data on retail prices of mobile broadband for defined by OECD set of mobile internet usage baskets corresponding to different usage profiles. Based on the price levels analysed countries were clustering into 4 categories, inexpensive, relatively inexpensive, relatively expensive and expensive clusters.

Figure 3. *Average price of 1GB mobile data transfer [in PLN] and the percentage variation of prices in Poland for different data transfer limits between 2014 and 2020*



Source: *Own elaboration based on the Office of Electronic Communications reports (UKE, 2014, 2018, 2020).*

According to EC analysis, in almost every case (i.e., for type of basket and a year) Poland was classified as the inexpensive cluster. The exception was a few handset baskets in 2016, in which Poland was classified in the relatively inexpensive category. Furthermore, in 2020 Poland was one of a small number of countries which were qualified for the group of inexpensive countries in all usage baskets (EC, 2021).

Table 2 presents the prices of three selected usage baskets corresponding to low, medium and high data consumption in Poland and EU28 between 2015-2020. Since mobile broadband baskets underwent numerous changes related to the increase in demand, we present data-only baskets, which with minor exceptions (e.g. 20 GB basket appeared only in 2016) remained unchanged during the analyzed period.

Table 2. *Prices of mobile broadband [in EUR] for selected data-only baskets in Poland and the EU28 between 2015-2020*

	Basket 500MB			Basket 2GB			Basket 20GB		
Year	Poland	EU28	PL/EU28 [%]	Poland	EU28	PL/EU28 [%]	Poland	EU28	PL/EU28 [%]
2015	9.42	10.30	-8%	9.42	14.56	-35%	-	-	-
2016	11.48	10.12	13%	11.48	13.70	-16%	12.48	42.13	-70%
2017	4.29	8.97	-52%	6.41	12.66	-49%	12.21	33.12	-63%
2018	4.17	7.75	-46%	4.17	11.15	-63%	8.34	27.76	-70%
2019	1.99	7.11	-72%	2.05	9.96	-79%	7.57	23.81	-68%
2020	1.94	6.35	-69%	3.88	9.23	-58%	7.77	19.11	-59%

Source: *Own elaboration based on European Commission reports.*

We can see from Table 2 that in almost every case (except for one basket including the lowest data usage in 2016) prices for mobile broadband services in Poland were significantly lower compared to the EU28 average, even up to 79% for 2GB basket in 2019. The EC's findings thus confirm the good position of Polish consumers when it comes to the cost of mobile broadband compared to EU Member States.

4.3.2 Availability and quality of mobile Internet

After examining the structure of mobile service prices, we will also examine the two other measures determining the supply side of mobile broadband, i.e., availability and quality of service. For describing the availability of services we used the LTE coverage indicator published annually by the EC in Broadband Coverage in Europe reports presenting the progress of EU Member States in meeting the coverage objectives of the Digital Agenda.

This metric is a kind of population coverage measure, which better than territorial coverage defines actual access to the network, especially in case of remote low-density areas, where mobile networks are not well deployed (WIK-Consult, 2015). LTE coverage indicator defines the percentage of households staying in coverage areas of at least one LTE network. It is presented separately on a national basis (total LTE coverage) and for rural areas i.e. areas for which population density does not exceed 100 people per km2 (rural LTE coverage) (Figure 4).

The EC study reveals that between 2014 and 2020, the availability of 4G services in Poland has improved significantly, especially in rural areas, where in 2014 only 3.4% of households had access to the LTE network (with the EU average of 27%), while as of 2018 there is almost universal coverage in rural areas in Poland (rural LTE coverage reached 99.9%). The biggest increase in availability in LTE coverage (both nationally and in rural areas) was observed in 2016.

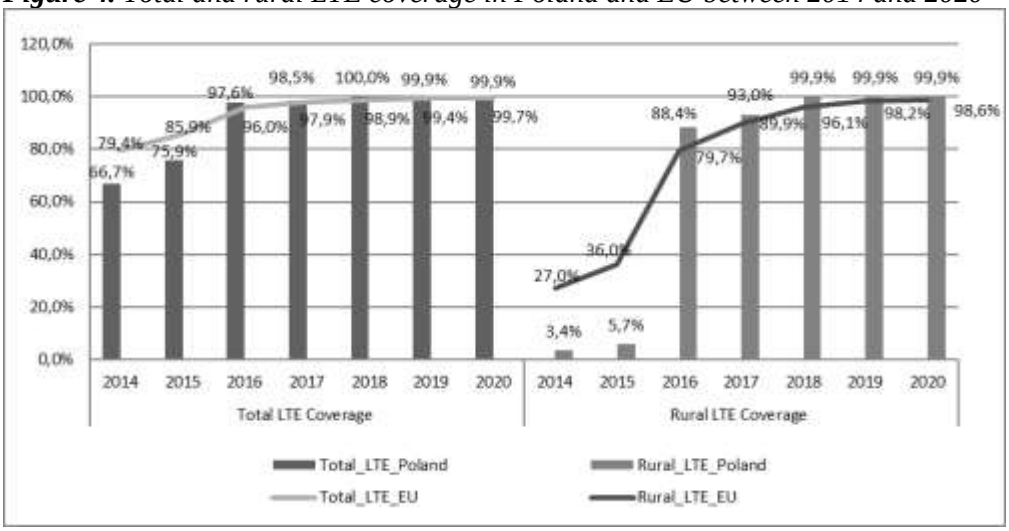
According to EC analysis, in 2016 Poland was one of the two countries (next to the UK) with the highest increase in service availability. In the case of rural areas, LTE coverage in 2016 grew by 82.7 percentage points (p.p.) reaching 88.4% (with the EU average of 79.7%). Moreover, since 2016, LTE coverage in Poland both nationwide and in rural areas has remained above the EU average, and since 2018 LTE coverage has reached near universal level.

The other important indicator for consumers is the quality of services measured by connection speed. Mobile network capacity is difficult to measure due to multiple factors (technological, terminal device-related, environmental etc) that could affect the speed and quality of internet connection. The quality of mobile networks is most often measured in a crowdsourcing model, in which data is collected from mobile users who have downloaded the appropriate testing application and run a test.

However, this method is exposed to sampling problems. Crowdsourcing systems are individually selected by users, so they may not be representative. In addition, the

number of tests carried out in a given country does not always correspond to the number of mobile Internet users.

Figure 4. *Total and rural LTE coverage in Poland and EU between 2014 and 2020*



Source: *Own elaboration based on EC`s Broadband Coverage in Europe reports*.

The results of such kind of measurement are therefore not definitive and should be treated with caution. It is recommended that final conclusions should be drawn based on data from at least two sources (Bennett, 2014).

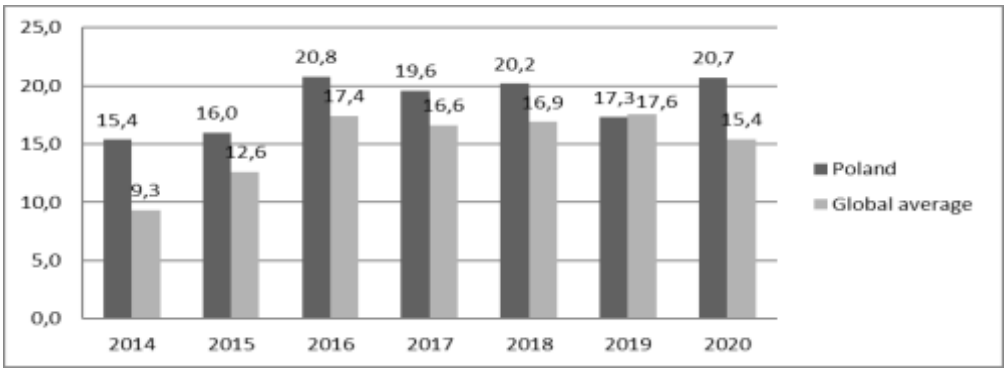
Data provided by network diagnostics companies were used to examine the speed of mobile Internet in Poland. They test the quality of communications networks around the world based on crowdsourcing systems and offer international comparisons. One of these companies is Opensignal.

Its research on download speeds confirms the good quality of mobile networks in Poland compared to other countries. Almost every year, download speed in Poland was significantly above the global average. The exception was in 2019 when the two measures achieved a similar level (Figure 5).

In addition to the standard download speed metric, Opensignal uses a proprietary measure called "Time on LTE/4G" metric to determine network quality. It measures the actual availability of 4G networks, by indicating the percentage of time during which users can actually connect to 4G networks in their respective countries.

This form of network quality measurement is less dependent on the quality of the device from which the user connects to the Internet and shows how consistently accessible 4G networks work.

Figure 5. *Average download speed [in Mbps] in Poland and the world between 2014 and 2020*



Source: *Own elaboration based on Opensignal`s The State of Lte reports.*

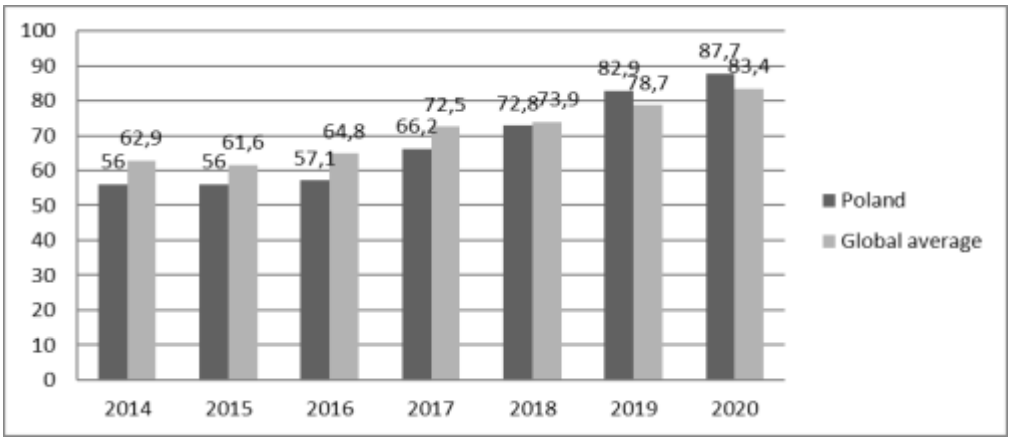
According to data presented on Figure 6, we can see an increase in 4G availability in Poland between 2014-2020. In 2014 and 2015 Polish consumers were able to receive LTE signal 56% of the time, while in 2020 LTE availability in Poland reached 87.7%. Comparing the Polish "Time on" metric against the average for all countries surveyed by Opensignal, we can see that until 2017, actual 4G availability in Poland was significantly lower than the global average (even by 7.7 p.p. in 2016). Since 2019, we can observe significant growth: in 2019 and 2020 the “Time on” metric in Poland increased to a level exceeding the global average by about 4 p.p.

Considering the aforementioned concerns over crowdsourcing test results two other data sources were also used to assess the speed of mobile Internet in Poland and relate it to other countries. They were: the quarterly data published up to the first quarter of 2017 by Akamai and data received from Ookla, which cover the period 2017-2020. Due to the almost complementary periods, data from these two different sources is presented in a common figure (Figure 7).

It is noticeable that Akamai's scores are significantly lower than Ookla's, which can be clearly observed especially for Q1 2017 which appears in both data sources. These discrepancies are most likely due to differences in the methodology applied. Nevertheless, both data sources confirm that the quality of downloads for Polish users maintained an upward trend over time and has changed in accordance with global trends.

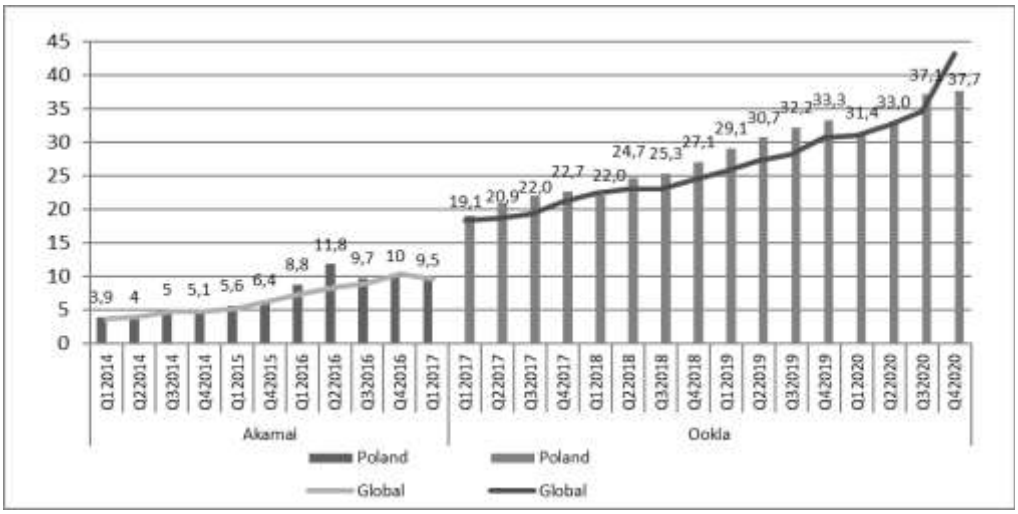
Almost throughout all analyzed period, average download speed in Poland was higher or close to the global average. An exception is Q4 2020 which may be resulted from the aforementioned fact that at that time the first 5G networks based on dedicated frequencies were set up in many countries, which significantly improved the quality of the Internet, allowing the provision of services with much better parameters than Polish 4G networks.

Figure 6. *„Time on LTE/4G" metric [in %] in Poland and the world between 2014 and 2020*



Source: *Own elaboration based on Opensignal`s The State of Lte reports.*

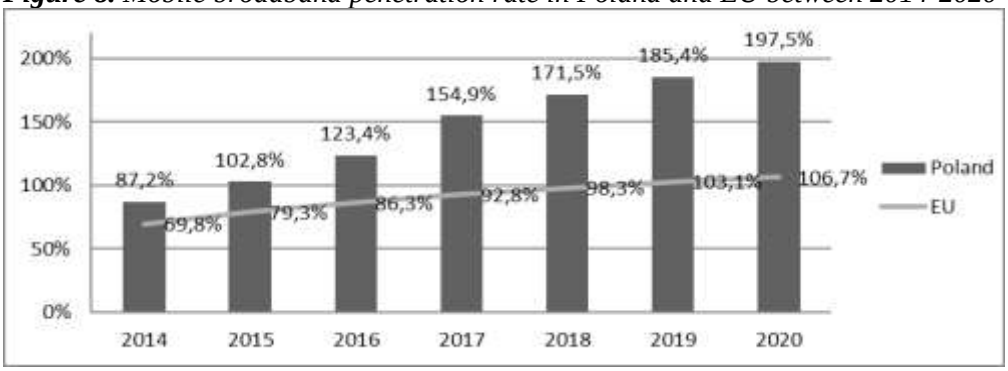
Figure 7. *Average download speed [in Mbps] in Poland and the world between 2014 and 2020*



Source: *Own elaboration based on Akamai`s state of the Internet reports and data provided by Ookla® based on John Paul II University in Biała Podlaska analysis of Speedtest Intelligence® data from 2017 to 2020. Ookla® trademarks used under license and reprinted with permission.*

The price as well as the availability and quality of mobile services in Poland are typically reflected in mobile penetration (take up). Indeed, Poland has been for years among the European leaders when it comes to mobile Internet usage and since 2017, in terms of mobile broadband penetration rate, it has been in a leading position. In 2020, mobile service penetration reached 197.5%, 90.8 p.p. higher than the EU average of 106.7%.

Figure 8. *Mobile broadband penetration rate in Poland and EU between 2014-2020*



Source: *Digital Agenda Scoreboard (as of December 2014-2020).*

5. Conclusions

This article aimed to investigate whether high prices paid by telecoms in Poland could have a negative effect on the Polish mobile internet market. Our conclusion could provide additional evidence for the discussed issue regarding the validity of the sunk costs argument in relation to mobile markets. To do this, we looked at consumer outcomes (price and quality of mobile services) before and after the Polish LTE auction.

Our study clearly showed that over the period considered the quality of the mobile Internet in Poland is constantly improving and the prices of mobile services are falling. We understand that due to the development of technology, a similar tendency can be also observed in other countries.

Thus, in order to reduce the weight of global trends and better capture the potential impact of high license fees we also benchmarked the Polish results with those of other countries and investigated whether there are any distortions in this relation. Potential changes in Poland's position compared to other countries after the 4G auction could provide some support for the theory that high spectrum prices have had a negative impact on the Polish mobile market.

We found no evidence for the statement that the high costs of spectrum have hurt Polish consumers. Prices for mobile services both before and after the spectrum auction were among the lowest in Europe. The quality and availability of services were also high compared to other countries. According to UKE mobile data transmission in Poland is the fastest growing service. In 2021, 9.1 million Polish consumers (23.9% of the population) used the Internet via dedicated mobile devices, accounting for 51% of all Internet users in the country.

The value of the mobile Internet market is also on an upward trend. In 2021 revenues from mobile access amounted to PLN 2.2 billion and accounted for almost

one-third (31%) of all Internet service revenues (UKE, 2022). According to research firm PMR, the growing trend in mobile market value will continue in the coming years, due to the operators' more-for-more strategy of offering more expensive packages with more data and the growing interest in voice tariffs that include access to 5G networks. However, PMR`s forecasts say that due to the high saturation of the market, the growth rate will be lower and lower every year (PMR, 2022).

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