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Assessing the Substitutability of Mobile and Fixed Internet: The Impact of 5G Services on Consumer Valuation and Price Elasticity

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Abstract: In this study, we explore the dynamics of consumer choices in the Polish telecommunications market, focusing on preferences and valuations for home fixed, home mobile, and purely mobile internet connections. Key attributes such as speed, latency, data limits, and cost are examined. Central to our research is the investigation of how the integration of 5G technology might influence demand elasticity. Using a detailed discrete choice experiment, we apply a mixed logit model with random parameters to analyze stated choice data, enabling us to unravel the complexities of demand elasticity, especially in terms of own- and cross-price elasticities. This approach facilitates an assessment of the degree of substitutability between fixed and mobile internet services.

Our findings indicate a moderate substitution effect between fixed and mobile internet services. Results from a Small but Significant and Non-transitory Increase in Price (SSNIP) test suggest that these markets should continue to be regulated separately, mirroring the distinct regulation observed in fixed and mobile telephony. Furthermore, simulations provide insights into potential future market shifts with the advent of 5G services. This paper contributes significantly to the discourse on fixed-mobile internet substitution and offers vital insights for defining markets in antitrust discussions, competitive agreements, and potential mergers within the telecom sector.

Keywords: Fixed-Mobile Internet Substitution, Consumer Preferences in Telecommunications, Mobile Broadband Access, Home Internet Connectivity, Discrete Choice Analysis, 5G Network Impact, Demand Elasticity in Internet Services, Stated Preference Methodology, Telecommunications Market Analysis, Price Elasticity in Internet Access

JEL codes: L96, D12, C25, L51, O33

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1. Introduction

As we navigate through the digital era, the internet has become an indispensable tool for global communication. By 2023, the number of active internet users surged to approximately 5.19 billion, nearly 65% of the global population, compared to just 0.4 billion in 2000. This dramatic rise is largely attributed to the rapid evolution of internet technology – marked by increased speeds, enhanced data transfer capacities, and reduced costs and latency. Initially monopolized by fixed-line connections, the internet landscape has undergone a radical transformation. In recent years, the development and increased availability of mobile internet access have blurred the lines between different types of internet services, particularly for users with lower demands. This shift is especially noticeable in regions lacking robust fixed internet infrastructure, where mobile internet, such as 4G-LTE, emerges as the sole viable option, bolstered by the introduction of unlimited data plans.

This evolving landscape raises a critical question: Is mobile internet a viable substitute for fixed internet? Answering this question is essential for defining the relevant market, a key consideration in antitrust proceedings, merger evaluations, and forming policies related to internet access provision. The significance of this question is further amplified by the rapid development of 5G technology, potentially reshaping the future dynamics of internet access.

Our study addresses this question using a Discrete Choice Experiment (DCE) to estimate consumers' stated preferences through a random parameters logit model. We analyze the own- and cross-price elasticities of demand, providing evidence to support the hypothesis that mobile internet could be considered a partial substitute for fixed-line internet. However, the results of the Small but Significant Non-transitory Increase in Price (SSNIP) test suggest that these markets should continue to be regulated separately. Thus, our key finding is that, as of 2018, mobile internet acts as a moderate substitute for fixed internet. We also explore how the expansion of 5G services might influence demand elasticity.

Focusing on the Polish telecommunications market, known for its competitive pricing and diverse operators, we provide insights that may be particularly relevant for medium and low-developed countries where internet access technologies are still evolving. Notably, before the launch of the UMTS network around 2004, available technologies offered limited speeds at high costs. The subsequent introduction of HSPA+ technology around 2008 marked significant improvements. Today, in some regions, mobile internet even surpasses the quality of fixed-line connections. However, limitations in transfer capacity, stability, and latency remain, influencing the choice between fixed and mobile internet, especially among specific user groups, such as online gamers who value stability and low latency. These ongoing improvements in mobile internet suggest that its role as a substitute for fixed internet may become more pronounced in the future.

The structure of our paper is as follows: Section 2 reviews the literature; Section 3 outlines our data and methodology; Section 4 presents the findings from our random parameters logit model, including estimations of own- and cross-price elasticities; Section 5 discusses policy implications, the impact of 5G services, and includes simulations; and Section 6 concludes the study.

2. Technological Evolution and Market Dynamics in Internet Connectivity

The debate on the substitution dynamics between mobile and fixed internet access forms a critical discourse in contemporary telecommunications research and offers an extensive review of this theme, highlighting a consensus among recent studies about the existence of a substitution relationship. However, the degree of this substitution remains a subject of ongoing debate, heavily influenced by the varying stages of infrastructural development and other intricate market factors unique to each country. This diversity in national contexts and consumer groups often results in contrasting findings, with some studies suggesting complementarity between fixed and mobile internet services. This section delves into a detailed literature review, examining diverse research perspectives to understand better whether various forms of internet access function as complementary or substitute goods in different global contexts.

2.1. Fixed-Mobile Substitution and Telephony

The discourse on fixed-mobile internet substitution has garnered considerable attention in recent research. Studies like Nakamura (2015) and Cincera et al. (2015) have explored this phenomenon from different analytical angles. Nakamura's use of a random parameters logit model revealed a substitution effect contingent on improvements in mobile broadband's tethering, quality of service, and security. Conversely, Cincera et al.'s linear regression analysis on European countries highlighted that the advent of 4G technology significantly amplified this substitution effect. Our study extends these findings by employing a more sophisticated random parameters logit model, offering deeper insights into the own- and cross-elasticities that drive consumer choices between fixed and mobile internet. It is important to note, as demonstrated by Grzybowski et al. (2014) and Leurcharusmee et al. (2017), that this substitution can vary greatly based on regional differences and consumer groups, such as gamers who prefer fixed internet for its lower latency.

In the realm of telephony, the shift from fixed to mobile services mirrors trends observed in internet access. Studies like Barth and Heimeshoff (2014) and Hoernig et al. (2015) have delved into the dynamics of fixed-mobile call substitution. Their findings indicate a strong and prevailing substitution effect over time, influenced by factors such as retail pricing strategies and market competition. Similarly, research by Briglauer et al. (2011) and Lange and Saric (2016) underscores the complexity of this transition, highlighting how factors like bundling strategies and voice-over-IP (VoIP) services interplay with consumer preferences. Pereira and Ribeiro (2011)'s analysis of the Portuguese market further illuminates how structural issues, like dual ownership of telephone and cable networks, can significantly impact market competition and social welfare.

The convergence of fixed and mobile services, both in internet access and telephony, depicts a rapidly evolving landscape driven by technological advancements and shifting consumer preferences. By outlining key studies and methodologies that have shaped our understanding of these dynamics, we are setting the stage for a comprehensive analysis of how these trends might evolve with future technological developments, such as the rollout of 5G networks.

2.2. Substitution Across Internet Technologies

The substitution between different types of internet access, particularly between DSL (Digital Subscriber Line) and cable modem, has been the subject of extensive study. Crandall et al. (2002) utilized a nested logit model, demonstrating that DSL and cable modem services belong to the same market and are substantial substitutes. This is supported by high own-price elasticity for DSL and cross-price elasticity for cable modems. Similarly, Cardona et al. (2009b) confirmed the substitutability of DSL and cable at both retail and wholesale levels, indicating a significant overlap in their market segments.

The transition from narrowband[1] to broadband[2] represents another critical aspect of internet technology substitution. Boik (2017) found notable elasticity between high-speed broadband options and lower-speed choices like satellite broadband and DSL. Supporting this, Pereira and Ribeiro (2011) analyzed the impact of structural separation in telecommunications, concluding that broadband access demand is less elastic compared to narrowband. Their study also revealed that broadband's market dynamics are distinct, as it is less influenced by the price of narrowband access. Parajuli and Haynes (2017) further explored this substitution using VAR models and Granger causality tests, observing a decline in dial-up subscribers with an increase in ADSL subscribers.

Investigations into market elasticities and consumer perceptions offer additional insights into these technologies' substitutability. Rappoport et al. (2003) noted that ADSL is a crucial substitute for dial-up access and that cable modems and ADSL are interchangeable to a significant extent. Ida and Kuroda (2006) differentiated narrowband from broadband, indicating that ADSL is less price-sensitive compared to other broadband forms like FTTH and CATV. Furthermore, studies by Dutz et al. (2009) and Grzybowski and Verboven (2016) have quantified these elasticities, shedding light on how consumers perceive these technologies, with some combinations being complementary and others substitutable.

The effect of bundling different services, including fixed voice, mobile voice, and internet services, on substitution patterns has also been analyzed. Madden et al. (2015) found that bundled services are generally seen as substitutes by consumers, indicating that packaging different telecommunications services does not necessarily lead to them being perceived as complementary.

In summary, the substitution between different internet technologies, including broadband, DSL, and narrowband, and their interplay with market factors like bundling presents a complex picture. These dynamics are crucial for understanding market behavior and guiding regulatory decisions in the telecommunications industry.

[1] Narrowband is characterized by a low-speed connection below 256 kbps with limited bandwidth capacity, e.g., dial-up internet or Integrated Services Digital Network (ISDN).
[2] Broadband is characterized by a high-speed connection above 256 kbps with high bandwidth capacity, e.g., cable internet, Digital Subscriber Line (DSL), Asymmetric Digital Subscriber Line (ADSL), Fiber to the Home (FTTH), Cable Television (CATV), or wireless 4G/5G internet.

2.3. Complementarity in Fixed and Mobile Internet Services

While much of the focus in telecommunications research has been on the substitution between fixed and mobile internet services, there is a growing body of literature exploring their complementarity. This aspect of the relationship between fixed and mobile internet services offers a nuanced view of consumer behavior and market dynamics, suggesting that these services can coexist and even enhance each other's value to users.

Studies in this area often delve into how consumers utilize fixed and mobile internet services in tandem to satisfy their diverse connectivity needs. For instance, mobile internet's flexibility and on-the-go accessibility complements the stability and high-speed connectivity of fixed internet, especially in scenarios involving heavy data usage or activities requiring reliable, continuous connections (Quaglione et al., 2020). This complementary relationship is particularly evident in user segments like business professionals and students, who may rely on mobile internet for communication and basic browsing while depending on fixed internet for more data-intensive tasks.

The evolution of technology significantly shapes the complementary nature of these services. Research by Grubesic and Mack (2015) highlighted how advancements in mobile technologies do not necessarily replace fixed internet services but rather contribute to a more diverse and flexible internet ecosystem. This concept of technological synergy is pivotal for predicting future trends in internet usage.

Acknowledging the complementarity between fixed and mobile internet also carries policy implications. As argued by Fransman (2010), this recognition is crucial for developing balanced policies that foster growth in both areas. Policymakers are encouraged to consider these insights, as seen in the policy analysis work of Cambini and Jiang (2009), to promote an equitable and innovative telecommunications sector.

In summary, understanding the complementarity between fixed and mobile internet services provides a more nuanced view of the telecommunications market. This perspective is vital for a comprehensive understanding and for anticipating how changes in technology and consumer behavior might shape the future of internet connectivity.

2.4. Emerging Technologies and Future Trends

At the forefront of emerging technologies in telecommunications is the rollout of 5G networks, poised to revolutionize internet connectivity. 5G technology is central to new cross-cutting industrial applications, leveraging denser, highly reliable, and ultra-fast exchange of information. It promises unprecedented speeds, reduced latency, and enhanced capacity, potentially reshaping consumer behavior and market dynamics. 5G is arguably not just an incremental improvement over 4G but a transformative technology that could enable new use cases, from IoT proliferation to smart city integrations.

The introduction of 5G is expected to significantly influence consumer preferences. Research by Takano (2023) suggests that the enhanced capabilities of 5G, such as higher data rates and lower latency, might shift consumer reliance more toward mobile internet, even in scenarios traditionally dominated by fixed broadband. This shift could be more pronounced in regions with underdeveloped fixed-line infrastructure, as indicated in the studies by Lee and Lee (2010). On the other hand, some researchers argue that 5G is unlikely to revolutionize human-to-human communications (Mendonça et al., 2022). Indeed, mobile network operators struggle to utilize 5G in ways that generate new sources of revenue (Whalley and Curwen, 2024). The business case for 5G is affected by substantially higher per-subscriber rollout costs relative to the 4G network due to denser cell architecture (Lehr et al., 2021). Additionally, 4G technology remains mostly sufficient for common services like social media and video streaming. The only enhancement to existing services that 5G can possibly bring is immersive and virtual reality applications or 8k streaming. According to industry projections, these enhanced applications are likely to remain niche in a saturated mobile broadband market.

Looking beyond 5G, the horizon of telecommunications technology holds further transformative potential. Innovations like edge computing, integrated AI, and advanced IoT applications are expected to create a more interconnected and intelligent network ecosystem. These advancements could lead to more personalized and efficient network services, tailoring connectivity solutions to individual user needs and usage patterns.

The evolution of these technologies also brings about new challenges in market dynamics and regulation. The widespread adoption of 5G and subsequent technologies will necessitate revisions in current regulatory frameworks, addressing issues like spectrum allocation, data security, and infrastructure sharing. Moreover, there will likely be a need for strategic collaborations between service providers, technology developers, and regulatory bodies to fully leverage the benefits of these emerging technologies.

Emerging technologies, particularly 5G and its successors, are set to redefine the telecommunications landscape. They offer not just improved connectivity but also a platform for innovative applications and services. Understanding their potential impact on consumer preferences and market dynamics is crucial for stakeholders to adapt to the rapidly evolving digital world.

3. Methodology and Data

3.1. Discrete Choice Experiment and Stated Preferences

In our study, we have employed the DCE methodology, a robust tool in stated preference research. This approach is particularly suited to analyzing complex consumer behaviors and preferences in scenarios where direct market data are limited or unavailable.

3.1.1. Concept and Relevance

DCE, grounded in Random Utility Theory (McFadden, 1974), involves presenting respondents with sets of hypothetical choices with different combinations of attributes (in our case, such as connection speed, latency, data transfer limits, and cost, which vary across service types like home fixed, home mobile, and mobile internet). This approach effectively captures nuanced data about consumer preferences and provides insights into the trade-offs consumers make, making it invaluable for understanding how individuals value various aspects of a product or service (Carson and Czajkowski, 2014).

The impending widespread adoption of 5G technology makes understanding potential shifts in consumer preferences crucial. DCE, with its ability to simulate market scenarios that do not yet exist, such as the full deployment of 5G services, provides valuable foresight. This aspect of DCE is crucial for stakeholders strategizing for upcoming market shifts and aligns with the approaches suggested by Czajkowski and Sobolewski (2016b).

Our application of DCE is methodologically rigorous. Our study design and implementation adhered to the guidelines and best practices suggested by Dillman et al. (2014), Mitchell and Carson (1989), Arrow et al. (1993), Bateman et al. (2002), Boyle (2017) and Champ et al. (2003), ensuring reliability and applicability of our findings. We utilized a Bayesian D-efficient experimental design optimized for the random parameters logit model estimation to enhance the statistical efficiency of our preference parameter estimations (Huber and Zwerina, 1996; Sandor and Wedel, 2001; Scarpa and Rose, 2008).

3.1.2. Design of the Experiment

In our DCE, the design was critical for capturing the nuances of consumer preferences in the Polish internet services market. We focused on a setup that would resonate with real-world scenarios while aligning with our research objectives.

Labeled Alternatives: The Polish internet market offers a variety of access methods, including xDSL (X Digital Subscriber Line), CATV, LAN/Ethernet, FTTH, WLAN/WiMax/other FWA (Fixed Wireless Access), and mobile networks (2G/3G/4G/5G modems). However, our preliminary literature review and focus group discussions indicated that consumers generally do not differentiate in detail between these various methods. To address this, we categorized the services into three broad groups:

1. **Home Fixed internet (HF):** This category encompasses traditional fixed-line internet access methods such as xDSL, CATV, and FTTH. It represents the standard home internet setup, offering various speed and data limit options.
2. **Home Mobile internet (HM):** This option includes fixed broadband access via radio technologies like WLAN, WiMax, and other FWA access types. It represents a more flexible home internet option than traditional fixed-line services, although with the same user experience (stability, no dropouts, etc.). Fixed connection between customer premises and 4G or 5G mobile network cell, involves network slicing to separate mobile service from residential mobile broadband. Both slices have to be optimized for performance according to different quality of service requirements.

3. **Mobile internet (MO):** This category includes internet access via mobile networks, relevant for consumers using dedicated mobile modems or mobile data on their devices. It reflects the increasing trend of mobile internet usage.

We selected four key attributes with varying levels for the DCE based on their relevance and impact on consumer choices: link speed, latency, data transfer limit, and cost. Table 1 shows attribute levels for specific alternatives.

Table 1. Attribute levels used in hypothetical internet access offerings

	Home Fixed internet	Home Mobile internet	Mobile internet
Link speed	• 10 Mb/s • 20 Mb/s • 50 Mb/s • 100 Mb/s • 200 Mb/s • 500 Mb/s • 1000 Mb/s	• 1 Mb/s • 2 Mb/s • 5 Mb/s • 10 Mb/s • 20 Mb/s • 50 Mb/s • 100 Mb/s • 200 Mb/s	• 1 Mb/s • 2 Mb/s • 5 Mb/s • 10 Mb/s • 20 Mb/s • 50 Mb/s • 100 Mb/s • 200 Mb/s
Latency	• 100 ms • 50 ms • 15 ms	• 500 ms • 250 ms • 100 ms • 50 ms	• 500 ms • 250 ms • 100 ms • 50 ms
Data transfer limit	• Unlimited	• 50 GB • 100 GB • 200 GB • Unlimited	• 1 GB • 2 GB • 5 GB • 10 GB • 20 GB • 50 GB • 100 GB • 200 GB • Unlimited
Cost	• 10 PLN • 20 PLN • 30 PLN • 40 PLN • 50 PLN • 60 PLN • 70 PLN • 80 PLN • 90 PLN • 100 PLN	• 10 PLN • 20 PLN • 30 PLN • 40 PLN • 50 PLN • 60 PLN • 70 PLN • 80 PLN • 90 PLN • 100 PLN	• 10 PLN • 20 PLN • 30 PLN • 40 PLN • 50 PLN • 60 PLN • 70 PLN • 80 PLN • 90 PLN • 100 PLN

Note: The exchange rate of the National Bank of Poland was 1 USD = 3.82 PLN (October 31, 2018). Purchasing power parity (PPP) based on OECD data for 'National currency units/US dollar' in 2018 for Poland was 1.7.

In designing the choice sets, we considered the need for realistic and comprehensive scenarios. This approach included combinations of attributes and levels that consumers are likely to encounter in the market, thereby enhancing the validity and applicability of our findings. Figure 1 illustrates a sample choice set used in the survey. Participants were instructed to select one or more services, allowing them to opt for combinations that best represented their real-life decision-making processes. As a result, the alternatives available to respondents consisted of three stand alone services (HF, HM, MO) and four combinations (HF+HM, HF+MO, HM+MO, HF+HM+MO), in addition to the 'opt-out' alternative ('No paid internet access').

Figure 1. Sample Internet Service Selection Scenario

Which of the offerings in the table below would you choose for yourself and your household, **if these were the only ones available to you**?

Situation 1	Home Fixed internet	Home Mobile internet	Mobile internet	No paid internet access
Link speed (average download time of a movie)	100 Mb/s (2 min)	30 Mb/s (6 min)	15 Mb/s (12 min)	
Latency	15 ms	50 ms	250 ms	
Data transfer limit	Unlimited	100 GB	20 GB	
Cost for your household	50 PLN / month	30 PLN / month	40 PLN / month	0 PLN / month
Your choice: • (you can "buy" more than one offer)	☐	☐	☐	☐

This experiment allowed us to model the coefficients of respondents' assumed utility function associated with any of the alternatives as follows::

$$U = \beta_{HF}HF + \beta_{HM}HM + \beta_{MO}MO + \beta_{HF+HM}(HF+HM) + \beta_{HF+MO}(HF+MO) + \beta_{HM+MO}(HM+MO) + \beta_{HF+HM+MO}(HF+HM+MO) + \beta_{Speed}\log(Speed) + \beta_{Latency}\log(Latency) + \beta_{Transfer}\log(Transfer) + \beta_{Cost}Cost \quad (1)$$

where HF, HM and MO and their combinations are dummy variables that correspond to alternative specific constants associated with the possible combinations of the available services (relative to the baseline – no paid internet access) and *Speed*, *Latency*, *Transfer* and *Cost* are continuous variables characterizing technical parameters of the services.[3]

The design of our DCE was tightly aligned with our research objectives, aiming to understand consumer valuation and preferences across different types of internet connections. By categorizing internet access methods into HF, HM, and MO and selecting relevant attributes, we captured the complexity of consumer decision-making in this dynamic market. This strategic blend of theoretical rigor and practical market understanding ensured that our experiment was both methodologically sound and aligned with real-world consumer behaviors in the Polish internet services market.

3.2. Survey Development and Data Collection

The survey, designed as a key instrument for our study, was structured to incorporate the DCE as its core component, alongside additional questions to capture relevant socio-demographic information and internet usage patterns. The survey's design and implementation were informed by rigorous pre-testing, including consultation with telecommunication and survey design experts, pilot studies and focus group discussions, ensuring that the questions were both clear and relevant to our target audience. This methodological approach was intended to not only align with our research objectives but also to facilitate a deeper understanding of the dynamic consumer preferences in the evolving landscape of internet services.

The data collection process for our survey was organized to capture a representative sample of Polish internet users, ensuring the reliability and applicability of our findings to the broader population. The survey was administered as a Computer Assisted Web Interview (CAWI). To ensure representativeness, our target demographic encompassed a broad range of internet users across Poland, with sample quotas reflecting the diversity in age, gender, income levels, and urban-rural distribution (a table summarizing the key characteristics of the sample is available in the online supplement[4]). This comprehensive demographic approach was instrumental in capturing

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[3] We tested several functional forms and found that using the logarithm of *Speed*, *Latency*, and *Transfer* result in the best model fit.

[4] The online supplement, containing data, software codes, additional results is available from <blinded for review, attached at the end of the paper>

varied consumer preferences and usage patterns, providing a holistic view of the market. The geographic scope spanned across the country, including both urban centers and rural areas, to ensure that the data captured a wide spectrum of internet infrastructure and accessibility scenarios prevalent in Poland.

The data collection phase spanned two months, from October to November 2018. A total of 5,204 respondents completed the survey, each participating in twelve choice sets along with additional questions. The high level of engagement can be attributed to the survey's user-friendly design and the relevance of the subject matter to the respondents' daily internet usage experiences. Moreover, throughout the data collection process, quality checks were consistently performed to ensure the accuracy and reliability of the responses. In instances of incomplete or inconsistent responses, follow-up measures were employed to clarify or rectify the data, thereby maintaining the integrity of our research.

3.3. Methodology

3.3.1. Analytical Approach

In the realm of telecommunications research, particularly when examining substitution effects, methodological approaches have significantly evolved. Earlier studies predominantly relied on simpler models such as the logit (Kridel et al., 1999; Lee et al., 2011; Narayana, 2010; Rodini et al., 2003), ordered logit (Flamm and Chaudhuri, 2007), and linear probability models (Sinai and Waldfogel, 2004). Later, more nuanced models like nested logit (Cardona et al., 2009a; Crandall et al., 2002; Dutz et al., 2009; Ida and Kuroda, 2006; Madden et al., 2015; Rappoport et al., 2003) and multinomial logit models (Bensassi-nour and Liang, 2019; Cardona et al., 2009a; Grzybowski et al., 2014; Ida and Kuroda, 2006; Liang and Petulowa, 2018; Liu et al., 2018) were more frequently used.

Our study follows this trend and adopts the Random Parameters Mixed Logit Model (RP-MXL), an advanced derivative of the Multinomial Logit Model. This choice aligns with recent scholarly trends favoring the RP-MXL for its robustness and adaptability (Czajkowski and Sobolewski, 2016a; Grzybowski et al., 2018; Grzybowski and Liang, 2015; Grzybowski et al., 2014; Grzybowski and Verboven, 2016; Liang and Petulowa, 2018; Liu et al., 2018; Nakamura, 2015; Pereira and Ribeiro, 2011; Sobolewski and Kopczewski, 2017; Srinuan et al., 2012).

The RP-MXL model originates from McFadden's Random Utility Model (1974), integrating a rationality axiom to predict consumer behavior effectively across diverse scenarios and population segments. The model decomposes the utility function into deterministic and stochastic components. The deterministic component assists in identifying factors influencing consumer choices, while the stochastic part accounts for the randomness inherent in decision-making processes.

A significant advantage of the RP-MXL model is its capacity to address the limitations of the simple multinomial logit model, particularly the restrictive Independent and Identically Distributed (IID) EV1 distribution assumption and the difficulty in capturing preference heterogeneity (Hensher et al., 2015; Louviere et al., 2000; Train, 2009). The RP-MXL model's flexibility allows for a diverse range of distributions (e.g., normal, log-normal, uniform, triangular) for variables, thereby accommodating both observable and unobservable preference heterogeneity (Czajkowski et al., 2014; Revelt and Train, 1998; Von Haefen and Phaneuf, 2008).

Furthermore, the RP-MXL model's ability to relax the Independence of Irrelevant Alternatives (IIA) assumption and its independence from the assumption of identically distributed random variables (IID) make it a more refined choice compared to its counterparts (Hensher et al., 2015; Train, 2009).

The formal representation of the utility derived from the RP-MXL model, including its stochastic and deterministic components, is detailed in the online supplement. This mathematical formulation lays the groundwork for our empirical analysis, providing the necessary framework to estimate implicit prices of (willingness to pay for) the choice attributes and the own- and cross-price elasticities of demand for different internet services, a pivotal aspect of our study.

The estimation of own- and cross-price elasticity involved analyzing how the probability of choosing a specific internet alternative (sensitivity of demand) changes in response to a variation in the price of specific service. This analysis is instrumental in understanding whether different internet services are considered substitutes or complements by consumers. A large number of studies on telecommunications recommend the use of elasticity analysis for examining whether two goods are substitutes or complements (Briglauer et al., 2011; Cardona et al., 2009a; Grzybowski and Verboven, 2016; Lange and Saric, 2016; Nakamura, 2015; Pereira and Ribeiro, 2011; Rodini et al., 2003; Srinuan et al., 2012).

3.3.2. Estimation Techniques

The model is estimated using the maximum likelihood method for the utility function parameters, conditional on individuals' observed choices and attribute levels associated with choice alternatives. Estimating the RP-MXL model requires the use of simulation methods because the formula for choice probability does not have a closed form. We thus apply a simulation procedure in which 10,000 parameters are drawn (scrambled Sobol draws; Czajkowski and Budziński, 2019) from their assumed parametric distributions, and for each - the logit formula is calculated. The simulated probabilities are given by the average over all draws and can then be used in a log-likelihood function (McFadden and Train, 2000).

Our application of the RP-MXL model also extends to simulating (random) implicit prices and price elasticities of demand. Implicit prices, also known as willingness to pay (WTP), represent the monetary value consumers assign to the attributes of internet access alternatives. Price elasticities, on the other hand, measure the responsiveness of consumer demand to changes in price. They are crucial in discerning whether internet access alternatives are perceived as substitutes or complements. The comprehensive approach of the RPL model, therefore, not only aligns with contemporary research methods but also significantly contributes to the depth and accuracy of our analysis, providing vital insights into consumer preferences and market dynamics. This, in turn, informs market behaviors and trends and aids in the formulation of relevant market definitions and regulatory policies.

The estimation of our models and simulations was conducted using custom-written software, specifically designed to work with the DCE package in Matlab (anonymized link). This software played a crucial role in efficiently processing the extensive dataset and in executing the complex calculations required for determining implicit prices as well as own- and cross-price elasticities. By harnessing advanced computational capabilities and sophisticated algorithms, we were able to accurately model and analyze consumer choice behavior. This approach enabled us to effectively interpret the impact of price variations on service preferences. For transparency and further exploration, the data, software codes used for estimation, and detailed results are made accessible in an online supplement, available at: anonymized link.

4. Results

This section outlines the key findings derived from our DCE analysis, specifically focusing on the preferences and substitutions between fixed (HF), home mobile (HM), and purely mobile (MO) internet alternatives.

4.1. Discrete Choice Analysis in WTP Space

The WTP space model offers an intuitive interpretation of utility function coefficients by expressing all parameters in a money-metric utility function. This representation directly translates consumer choices into monetary values, indicating the maximum price consumers are willing to pay for specific attributes of internet services. The transition from a traditional preference space model, as detailed in the online supplement, to a WTP space model involves scaling the utility function to integrate monetary metrics directly.

Our model's estimation in WTP space is depicted in Table 2. This model incorporates eight alternative-specific constants for the combinations of Home Fixed (HF), Home Mobile (HM), and Mobile internet (MO), with 'no choice' as the reference level. The parameter estimates represent consumers' valuation of various service attributes, such as speed, latency, data limits, and cost. During the estimation process, various combinations of transformations and parameter distributions were examined, and the final decision was based on the model with the best fit, considering factors such as the model's log-likelihood, McFadden's pseudo-R^2, Ben-Akiva-Lerman pseudo-R^2 and both the Akaike and Bayesian information criteria. Ultimately, the logarithmic transformations of the speed, latency, and transfer variables were adopted. Similarly, the latency, transfer, and cost variables' parameters are derived from a log-normal distribution, while the parameters for the speed variable and alternative-specific constants are from a normal distribution. The Ben-Akiva-Lerman pseudo-R^2 of nearly 29% suggests that the model specifications and transformation effectively capture a substantial portion of the variability in the data, supporting its utility in predictive analysis.

The inclusion of logarithmic transformations is intended to better capture the non-linear dependencies of the parameters, allowing for the differentiation that, for example, an increase in speed from 100 Mb/s to 200 Mb/s is more significant than an increase from 800 Mb/s to 900 Mb/s.

Additionally, the advantage of the random parameters logit model specification is that it enables the estimation of a model with the aforementioned transformations, focusing on comparing the utility of individual alternatives rather than calculating the exact utility value. It is also worth noting that the random parameters logit model relaxes the Independence of Irrelevant Alternatives (IIA) axiom, implying that the choice between two alternatives does not depend on unrelated alternatives. This is a key observation that makes our approach suitable for analyzing fixed-to-mobile substitution.

Table 2. Random parameters logit model estimates in WTP space

		Means			Standard Deviations		
	Distribution	Coef.		Std. error	Coef.		Std. error
HF	Normal	-0.9446	***	0.2308	4.0767	***	0.2032
HM	Normal	-3.8913	***	0.2841	4.0791	***	0.2043
MO	Normal	-4.3314	***	0.2826	4.2809	***	0.1960
HF+HM	Normal	-5.2350	***	0.3004	4.5078	***	0.2043
HF+MO	Normal	-4.9525	***	0.2969	4.5762	***	0.2008
HM+MO	Normal	-6.0259	***	0.3113	4.6618	***	0.2015
HF+HM+MO	Normal	-7.7040	***	0.3614	4.8339	***	0.2020
log(Speed (Gb/s))	Normal	0.1503	***	0.0052	0.1330	***	0.0054
-log(Latency (100 ms))	Log-Normal	0.0273	***	0.2545	0.0312	***	0.0773
log(Transfer (100 GB))	Log-Normal	0.0623	***	0.0728	0.0359	***	0.0247
-Cost (100 PLN)	Log-Normal	1.5729	***	0.0217	1.2133	***	0.0154
Log-likelihood		-85,847.80					
McFadden's pseudo-R^2		0.1470					
Ben-Akiva-Lerman's pseudo-R^2		0.2864					
AIC/n		2.7519					
BIC/n		2.7630					
Observations (n)		62,448					
Respondents		5,204					
Parameters		77					
Number of Sobol draws		10,000					

Note: Significance levels: * p <0.1, ** p <0.05, *** p <0.01

Each attribute's valuation is deduced from these estimates, providing insights into consumer priorities. In addition, our analysis reveals interesting comparative valuations among the attributes. Consumers showed the highest WTP for speed improvements, indicating a strong preference for faster internet connections. A 1% increase in speed, for instance, corresponded to a WTP of an additional 15 PLN (per month). In contrast, a 1% decrease in latency and a 1% increase in data transfer limit were valued at 3 PLN and 6 PLN, respectively. These findings illustrate the relative importance of speed over other attributes like latency and data limits in consumer preferences.

The means and standard deviations of these parameters were found to be significant at the 1% level, indicating robustness in our model estimations. The signs of the WTP estimates align with theoretical expectations, suggesting that consumers value increases in speed and data limits while preferring lower latency and cost.

Significantly, the standard deviations for all attributes were different from zero, underlining the presence of preference heterogeneity among consumers. A higher standard deviation parameter indicates greater heterogeneity in consumer preferences. This heterogeneity suggests that different consumer segments place varying levels of importance on these attributes, reflecting the diverse needs and preferences within the market.

The model incorporates eight alternative-specific constants for the combinations of HF, HM, and MO, with a 'no choice' option as the baseline. This approach allows us to examine preferences for each internet service type in isolation. The constants represent the intrinsic value consumers place on each service type, independent of other attributes like speed, latency, or cost.

From our analysis, HF emerged as the most preferred option among consumers. This preference underscores the importance of stability and reliability, often associated with fixed-line connections. In contrast, the combination of HF, HM, and MO was the least preferred option, indicating potential consumer concerns about complexity or redundancy in having multiple types of internet services.

The preference for HF can be attributed to several factors, such as the perceived reliability, faster speeds, and consistent connectivity it offers, which are crucial for activities like streaming, gaming, and telecommuting. HM, while also preferred, seems to be less favored compared to HF, likely due to limitations in speed and reliability. MO, despite its flexibility and on-the-go access, appears to be the least preferred as a standalone option, possibly due to concerns about data limits, speed, and network coverage.

The observation that a combination of HF, HM, and MO is least preferred is particularly revealing. It suggests that consumers may find the idea of managing multiple internet services cumbersome or unnecessary. This insight is potentially useful for service providers, as it highlights the potential for integrated service packages that combine the advantages of fixed and mobile internet without overwhelming the consumer.

By comparing the sizes of the alternative-specific constants, we gain valuable insights into the relative desirability of these internet services. HF's higher preference score indicates its dominant position in the market. However, the moderate preference for HM and MO suggests that these services have their niches, likely catering to specific consumer needs and contexts.

The analysis of consumer preferences in our study reveals a clear hierarchy in the valuation of different internet service types. HF stands out as the most preferred service, reflecting its perceived advantages in terms of reliability and speed. The less pronounced but still significant preferences for HM and MO underscore the importance of flexibility and mobility in internet access. These findings offer a nuanced understanding of the Polish internet market, shedding light on consumer priorities and potential areas for service differentiation and innovation.

4.2. Elasticity Estimations

In this section, we delve into the elasticity estimations for HF, HM and MO services. Understanding the elasticities is essential for comprehending how sensitive consumer demand is to price changes, a key factor in market dynamics and strategic pricing decisions. Table 3 presents our estimations of own- and cross-elasticities.

Table 3. Own- and cross-elasticities estimated for median characteristics values

	HF (service)	HM (service)	MO (service)	No access	Any access
Elasticities in relation to HF price change (std. err.)	-0.1843*** (0.0053)	0.2095*** (0.0071)	0.0829*** (0.0033)	0.3189*** (0.0158)	-0.0276*** (0.0017)
Elasticities in relation to HM price change (std. err.)	0.0879*** (0.003)	-0.3364*** (0.0093)	0.0639*** (0.0029)	0.1251*** (0.0066)	-0.0106*** (0.0007)
Elasticities in relation to MO price change (std. err.)	0.0443*** (0.0015)	0.0743*** (0.003)	-0.467*** (0.0148)	0.0853*** (0.0045)	-0.0073*** (0.0005)

Notes: The services labelled as HF, HM and MO represent all choice alternatives, including respective services. The median of respondents' internet characteristics (presented in Table 8 in the online supplement) are 50 Mb/s (speed), 50 ms (latency), unlimited transfer limit with cost of 40 PLN/month for HF alternative; 30 Mb/s, 100 ms, 20 Gb transfer limit with cost of 40 PLN/month for HM; and 20 Mb/s, 100 ms, 10 Gb transfer limit with cost of 75 PLN/month for MO. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Own-elasticity measures the responsiveness of demand for a service (a stand-alone alternative or included in a combination of services) to a change in its price.[5] In our study, the own-elasticities for HF, HM, and MO were found to be -0.1843, -0.3364, and -0.467, respectively. These values, being less than 1 in absolute terms, classify the demand for these services as inelastic. This inelasticity indicates that a 1% increase in the price of these services would result in a less than 1% decrease in demand of HF, HM or MO services (and the demand changes for the alternatives including only these stand-alone services are not substantially more price sensitive, with elasticities of HF, HM and MO alternatives estimated at -0.1971, -0.369, and -0.4943, respectively). The inelastic nature of these services suggests that consumers might not significantly reduce their usage in response to price increases, possibly due to the lack of viable alternatives or the essential nature of these services.

Cross-elasticity, in contrast, measures the impact of the price change of one service on the demand for another. Positive cross-elasticity values indicate a substitution effect between services. Our findings reveal that the cross-elasticities between HF, HM, and MO range from 0.0443 to 0.2095, suggesting that these services are moderate substitutes. This range implies that an increase in the price of one service type leads to a moderate increase in the demand for the other services. For instance, a significant price increase in HF might lead some consumers to consider HM or MO as viable alternatives, albeit not on a one-to-one basis.

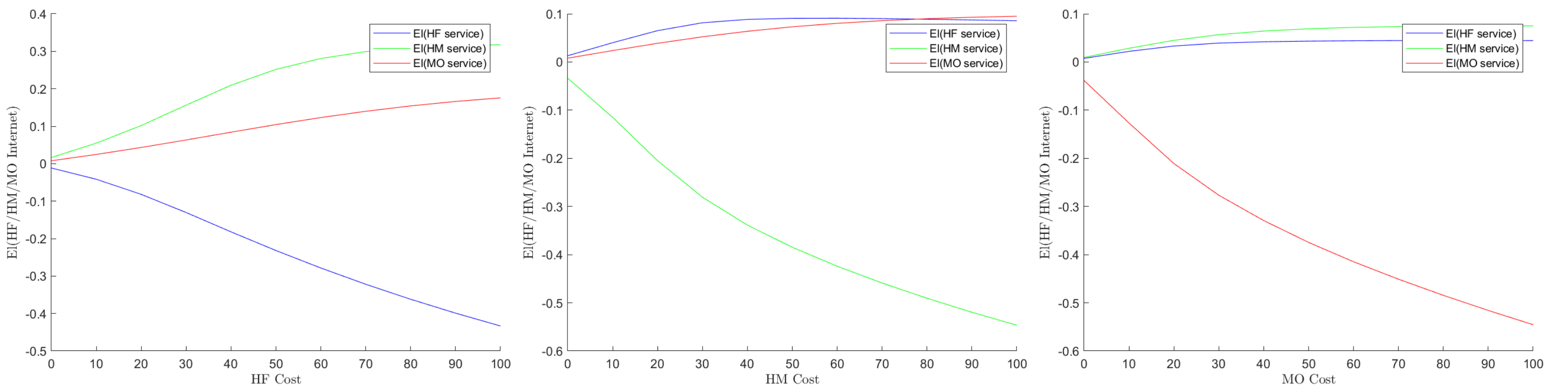
The inelastic own-elasticities suggest that price changes within each service type might not significantly alter consumer behavior. However, the moderate substitutability indicated by the cross-elasticities points to a competitive interplay between these services. Service providers might leverage this substitutability in their pricing and marketing strategies, potentially influencing consumer choice between fixed and mobile internet options.

Figure 2 provides a graphical representation of both own- and cross-elasticities in relation to changes in the prices of HF, HM, and MO services. This visual approach allows us to observe trends and patterns in elasticity that may not be immediately apparent from numerical data alone.

[5] Note that our discussion focuses on the changes in demand for the services as a result of price changes in these services. Detailed results, indicating how these price changes affect the demand for each of the alternatives are available in the online appendix. The online appendix also highlights how the elasticities change in relation to the simultaneous price change of several services.

It shows a decline in own-elasticities as the price increases, indicating a consistent inelastic demand across all service types.

Figure 2. Own- and Cross-Elasticities estimated for HF/HM/MO services in relation to HF/HM/MO price changes



Notes: The services labelled as HF, HM and MO represent all choice alternatives, including respective services. The first chart shows elasticities in relation to HF price changes, the second – HM, and the third – MO.

Regarding cross-elasticities, an increase in the price of one service type leads to a rise in the demand for the other service types. The graphical representation in Figure 2 illustrates that as the cost of, say, HF increases, the demand for HM and MO services slightly increases, indicative of a substitution effect, albeit moderate.

These visual insights are important in understanding market dynamics. The inelastic nature of own-elasticities suggests that service providers might have some flexibility in pricing without significantly affecting demand. However, the positive cross-elasticities highlight an underlying competitive tension between these services, suggesting that significant price changes could shift consumer preferences between fixed and mobile internet services.

5. Discussion and Policy Implications

Our study's elasticity estimations provide a basis for the analysis of the degree of substitution between fixed and mobile internet services, offering insights into how consumers perceive and choose between these service types. Our findings reveal a moderate substitution effect between fixed and mobile internet. This effect is consistent with observations in other mature telecommunications markets. As mentioned previously, our results align with those found in recent literature. However, it is important to note that there is a range of own-elasticity values reported in various studies. For instance, mobile own-elasticity values vary from -0.1 (Grzybowski and Verboven, 2016) to -5.05 (Nakamura, 2015), with other studies reporting values between these extremes, such as -0.22 (Lange and Saric, 2016) and -3.623 (Srinuan et al., 2012). For fixed-line access, own-elasticities range from -0.316 (Lange and Saric, 2016) to -3.56 (Grzybowski et al., 2014). Similarly, the own-elasticities for broadband technologies vary from -0.22 (Flamm and Chaudhuri, 2007) to -2.059 (Pereira and Ribeiro, 2011). Narrowband technologies show own-elasticities ranging from -0.773 Cardona et al. (2009b) to -3.325 (Ida and Kuroda, 2006). These studies across various markets suggest a common consumer behavior pattern where fixed and mobile internet services are seen as partly substitutable but not perfectly interchangeable.

In contrast to the own-elasticities, the cross-elasticities in our study exhibit positive signs, indicative of a substitution effect between fixed and mobile internet. This effect occurs because an increase in the price of one service leads to an increase in the demand for another service. In the context of our study, this translates to a higher probability of consumers choosing a different internet service option when the price of their current choice increases. However, it is important to note that these cross-elasticities are also inelastic. The values we obtained range from 0.0443 to 0.2095, suggesting that fixed and mobile internet services are moderate substitutes. The results for cross-elasticity related to the substitution from fixed to mobile internet show less variation compared to own-elasticity values, ranging from a low of 0.0009 (Grzybowski and Verboven, 2016) to higher values such as 0.811 (Srinuan et al., 2012) or 0.86 (Grzybowski et al., 2014). Generally, in most related studies, the cross-elasticity values are observed to lie between 0 and 0.5 (Bae et al., 2014; Cardona et al., 2009a; Kridel et al., 1999; Lange and Saric, 2016; Madden et al., 2015; Nakamura, 2015; Narayana, 2010; Oğuz et al., 2015; Rodini et al., 2003).

The own- and cross-elasticity values, detailed in our previous tables, underscore this moderate substitutability. For instance, while the own-elasticity values for HF, HM, and MO (Table 3) indicate a level of loyalty or preference for a specific service type, the cross-elasticity values reveal that consumers may consider other types when faced with price changes or service alterations.

For service providers, understanding this substitution effect is crucial for developing competitive strategies and pricing models. The moderate substitution effect between fixed and mobile internet indicates a nuanced consumer decision-making process, where factors beyond price, such as service quality, reliability, and personal usage habits, play significant roles. It implies that providers can attract customers from competitors with strategic improvements in service offerings or pricing adjustments. However, the inelastic nature of the demand also suggests that consumers might not readily switch providers for minor changes in price or service quality.

5.1. Market Substitution Analysis

Our elasticity findings can also be used for defining the relevant market in telecommunications, particularly in the context of antitrust proceedings and competitive agreements. According to the principles outlined by Pitofsky (1990), a relevant market encompasses products or services that are close substitutes in terms of price, attributes, and consumer use. The accurate definition of a relevant market is pivotal for regulatory bodies in making informed decisions about competition and consumer welfare.

One widely accepted method for market definition is the Small but Significant and Non-transitory Increase in Price (SSNIP) test, also known as the hypothetical monopolist test. This test, as mentioned by Werden (2003) and others, assesses whether a small (usually 5-10%) but significant price increase would lead consumers to switch to another product, indicating a substitution effect. It can also be adjusted to test whether the substitution effect for certain goods and services is strong enough to consider them almost perfect replacements for each other, and hence, their markets need to be merged into one combined market. The test was used or referred to in a few articles about fixed-to-mobile substitution and other telecommunications-related studies (Briglauer et al., 2011; Cardona et al., 2009a; Grzybowski et al., 2014; Lange and Saric, 2016; Srinuan et al., 2012; Vogelsang, 2010; Yannelis et al., 2009).

The SSNIP test can be reformulated into a critical value of market demand elasticity, $\varepsilon_{critical}$, defined as $\frac{1}{m_0+t}$, where m_0 represents the Lerner index for the hypothetical single firm (calculated as $\frac{price-margincal\ cost}{price}$) and t is the minimum price increase considered significant in the test. The test identifies the critical absolute level of elasticity necessary to leave the profits unchanged following a price increase. In our study, the threshold for t is set at 5%. Given that m_0 falls within the range [0,1], $\varepsilon_{critical}$ consequently ranges between [0.95,20]. Referring to the own elasticity values for median characteristics (as shown in Table 3 and Figure 2), which are -0.1843, -0.3364, and -0.467 for HF, HM, and MO, respectively, we observe that these values fall below the critical level in absolute terms. This indicates that a price increase of any single analyzed service would be profitable for a firm, pointing to very low substitutability between services and, consequently, a monopolistic nature of each individual service market. Conversely, if the own elasticity values exceeded $\varepsilon_{critical}$, it would suggest that the closest substitutes should be included to broaden the scope of the relevant market. Based on estimates of own price elasticities obtained from the choice model, we conclude that the relevant markets are well-defined for all analyzed product alternatives, and there is no need to expand market boundaries or merge service markets for regulation.

In our analysis of the telecommunications market, characterized by a concentrated oligopoly, the significant scale economies inherent to network industries present unique challenges. These challenges include the difficulty in precisely calculating marginal costs due to the complex infrastructure investments and the operational scale required. Consequently, the observed prices in such markets may not transparently reflect their proximity to a competitive benchmark, potentially nearing those set by collective monopolists. This ambiguity in the pricing benchmark crucially underscores the importance of considering a wider range of price scenarios in our elasticity analysis. By evaluating elasticities not just at observed prices but across a spectrum of higher and lower prices, we ensure a robust assessment of potential pricing strategies. Our comprehensive elasticity analysis confirms consistently low elasticity across all scenarios, suggesting that firms would not benefit from any price increases, regardless of the assumed level of competitive pricing. This thorough approach mitigates the risk of false negative outcomes in the SSNIP test, a critical consideration highlighted by the 'Cellophane paradox,' where existing prices might mask the true competitive dynamics of the market (Posner, 1976).

Our SSNIP test analysis reveals that the own-elasticity values for HF, HM, and MO do not reach the critical threshold necessary to consider merging these services into a single market. This finding is supported by the literature on fixed-to-mobile substitution (e.g., Briglauer et al., 2011; Srinuan et al., 2012) and indicates that fixed and mobile internet services in the Polish market should continue to be treated as separate markets for regulatory purposes. Therefore, our study suggests that, currently, the markets for fixed and mobile internet access are sufficiently distinct to warrant separate consideration in antitrust cases and policy discussions.

5.2. Implications of 5G Technology

In this subsection, we discuss the anticipated implications of the emerging 5G technology on the dynamics of the legacy telecommunications market, specifically focusing on its potential to alter the existing patterns of fixed and mobile internet usage.

A notable limitation of our study is the reliance on survey data from 2018. Since that time, the preferences, demand, and infrastructure may have evolved substantially. To partially address this limitation, we integrate the characteristics of current offerings into our calculations and simulations, as detailed in Table 4 and Table 5. By assuming that preferences remain stable over time, we evaluate whether recent infrastructure developments (driven by investments in broadband and 5G networks) and changes in available offerings significantly influence the substitution effect between services and connection types. Furthermore, we explore the extent to which these changes affect developed areas compared to underdeveloped regions, specifically those lacking access to fixed broadband infrastructure and advanced fixed technologies like FTTH.

Therefore, our new simulations include counterfactual scenarios with 5G home mobile broadband access (HM5G), replacing 4G legacy home mobile broadband (HM). In terms of technical parameters, we draw from existing market offerings: the enhanced mobile broadband offers a 6-fold increase in speed (600 vs. 90 Mb/sec), 50% smaller latency (20 vs. 30 ms), and doubled data allowance (150 vs. 70 GB/month). The monthly subscription fee increases by 70% from 50 to 85 PLN. Above technical parameters and pricing correspond to 5G commercial offerings available in Poland in spring 2022. Clearly, 5G broadband service offered by telecommunication operators is a technically enhanced and more expensive version of mobile home broadband. Importantly, 5G access contains a limited monthly data allowance, which makes it still less attractive than fixed access. We apply the estimated demand model to the extended choice set to check whether the improvement in mobile internet parameters leads consumers to perceive HM5G as a viable alternative to fixed broadband or 4G mobile home access, potentially shifting the market dynamics and increasing substitutability across fixed and mobile broadband access. Should this be the case, the introduction of 5G technology could necessitate a reevaluation of competitive strategies among service providers and a potential recalibration of regulatory frameworks. If 5G effectively blurs the lines between fixed and mobile internet, regulators might need to reconsider current market definitions and competition policies.

The results of the counterfactual analysis, presented in Table 4, indicate that the introduction of 5G-enhanced home mobile internet (scenario B) has no impact on the substitutability of fixed broadband. Cross-price elasticities between HM/HM5G and HF change in the expected direction from 0.1025 to 0.2805 across baseline and counterfactual scenarios. The magnitude of this change and absolute values of cross-price elasticities are, however, very small, indicating that the overall level of substitution between HF and HM5G is minimal. This result is not unexpected, as the 5G mobile subscription is weakly inferior in parameters – HM5G has the same speed but higher latency and limited data allowance - but is more expensive than a fixed subscription (60 vs. 85 PLN). Similarly, the introduction of HM5G has no impact on the demand for mobile broadband, as indicated by the very low cross-price elasticity between MO and HM/HM5G (ranging from 0.0745 to 0.1252). In short, although 5G-enhanced mobile broadband access is superior to 4G subscription, its introduction does not fundamentally change the substitution patterns with existing access services and, hence, is not going to affect the definition of relevant markets. The above analysis has one important caveat, namely that it is carried out for existing 5G packages, which are quite expensive and thus considered economically less attractive than 4G packages by a large part of consumers. Additionally, 5G offerings are both more expensive and technically inferior to fixed home access, which explains the lack of impact on the substitution patterns. With further advancement in technical parameters combined with decreasing fees, the picture may change in the future. Thus broadband substitution will remain a valid research question in the years to come.

Table 4. Own- and Cross-Elasticities with Baseline and 5G Scenarios

		HF (service)	HM (service)	MO (service)	No access	Any access
Scenario A: Baseline (BSL)	Elasticities in relation to HF price change (std. err.)	-0.2534*** (0.0074)	0.2805*** (0.0092)	0.1387*** (0.0056)	0.4049*** (0.0204)	-0.0319*** (0.0021)
	Elasticities in relation to HM price change (std. err.)	0.1025*** (0.0034)	-0.4193*** (0.0117)	0.0965*** (0.0047)	0.1824*** (0.0091)	-0.014*** (0.0008)
	Elasticities in relation to MO price change (std. err.)	0.0473*** (0.0018)	0.0858*** (0.0038)	-0.4401*** (0.0129)	0.1152*** (0.0065)	-0.0089*** (0.0006)
Scenario B: Counterfactual (CFL)	Elasticities in relation to HF price change (std. err.)	-0.2508*** (0.0069)	0.2319*** (0.0079)	0.1683*** (0.0069)	0.5101*** (0.0243)	-0.0425*** (0.0026)
	Elasticities in relation to HM price change (std. err.)	0.1292*** (0.0039)	-0.5216*** (0.0165)	0.1252*** (0.0058)	0.1332*** (0.0067)	-0.0107*** (0.0007)
	Elasticities in relation to MO price change (std. err.)	0.0551*** (0.0023)	0.0745*** (0.0036)	-0.4629*** (0.0134)	0.1414*** (0.008)	-0.0115*** (0.0008)

Notes: The services labelled as HF, HM and MO represent all choice alternatives, including respective services. The internet characteristics for the BSL scenario are 600 Mb/s (speed), 10 ms (latency), unlimited transfer limit with cost of 60 PLN/month for HF alternative; 90 Mb/s, 30 ms, 70 Gb transfer limit with cost of 50 PLN/month for HM; and 30 Mb/s, 30 ms, 70 Gb transfer limit with cost of 60 PLN/month for MO. For the CFL scenario, the HM alternative was replaced by the HM5G alternative with 600 Mb/s (speed), 20 ms (latency), 150 Gb transfer limit with a cost of 85 PLN/month. The aforementioned attribute values were artificially selected to reflect the actual value of internet connection characteristics available on the Polish market in developed and underdeveloped areas. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

It is well established that infrastructure development plays a significant role in determining the availability and quality of internet services, particularly between urban and rural areas. Users in densely populated areas have access to fixed broadband infrastructure and advanced fixed technologies like FTTH. In contrast, rural areas often lack such infrastructure, making home mobile internet a more viable option. To observe the effect of this discrepancy between developed and underdeveloped areas, we extend our counterfactual analysis.

Additional simulations provide substitution patterns separately for developed and underdeveloped areas where fixed home broadband is unavailable, as shown in Table 5 (presented in the appendix). The results for developed areas (scenarios C and D) yield similar conclusions to those established in the pooled simulation above. For underdeveloped areas (scenarios E and F), we again note that existing 5G offerings have no impact on the substitution between home mobile and mobile broadband access services.

The rollout of 5G technology is likely to have varying impacts across regions. Our simulation shows that in developed areas with established fixed internet infrastructure, 5G might supplement rather than replace fixed services. However, in underdeveloped areas, 5G could significantly alter the market, possibly becoming the primary mode of internet access due to its superior performance compared to existing mobile technologies. Service providers and policymakers need to consider these regional disparities when designing internet services and regulatory frameworks. Tailored strategies that account for regional infrastructure and consumer preferences will be essential in ensuring equitable internet access and maintaining competitive markets.

While our results are specifically focused on the Polish telecommunications market, they offer valuable insights for various medium and low-developed countries where internet access technologies are still evolving. It is important to note, however, that several factors might enhance the potential for fixed-to-mobile substitution. These include the country's infrastructure, which often stems from the geographic characteristics of a given country or area, and usage patterns, which are particularly crucial for individuals who cannot afford a temporary loss of connection stability. In such scenarios, fixed and mobile internet connections are not likely to be considered substitutes. However, our simulations indicate a trend that by improving the characteristics of mobile internet, including reducing its cost, an increasing portion of society may begin to treat these connections interchangeably. The examination of fixed-to-mobile internet substitution is therefore crucial for the future, especially considering the rapid development of 5G/6G technologies. When fixed and mobile internet are considered substitutes, it becomes necessary to re-examine market definitions to prevent antitrust proceedings, competitive agreements, and potential mergers within the telecommunications sector that may not benefit consumers. Thus, the conclusions presented in this article extend beyond the Polish market and are applicable to countries with similar or less advanced technological development.

The 5G technology is anticipated to bring transformative changes characterized by higher speeds, reduced latency, and improved overall service quality. These improvements are likely to enhance the appeal of mobile internet services significantly. The study's projections suggest that as 5G technology becomes more widespread and considerably cheaper, it could alter the existing balance between fixed and mobile internet usage, increasing the substitutability of mobile internet. This raises important considerations for future market changes. As 5G technology develops and becomes more accessible, it will be crucial to reassess the market dynamics and consumer preferences. The transition to 5G could lead to a scenario where mobile internet not only complements but also competes more directly with fixed internet services. For this to happen, 5G broadband offerings have to contain unlimited data allowance.

Given these anticipated changes, there is a clear need for further research to monitor and analyze how the adoption of 5G technology impacts consumer behavior and market structures. Future studies should focus on understanding the extent to which 5G alters the perceived value and utility of mobile internet services compared to fixed services, while regulatory bodies and policymakers should be prepared to revisit and potentially revise the regulatory frameworks. The substitution patterns are likely to evolve with the 5G service life cycle, notably as the competitive pressure increases and pushes prices down.

Overall, the advent of 5G technology is poised to reshape the telecommunications landscape. Its full impact on consumer preferences, market dynamics, and regulatory frameworks will become clearer in the coming years. As such, continuous monitoring and analysis will be essential to understand and adapt to the changing market environment effectively.

6. Summary and Conclusions

Our study examines consumer choices in the Polish telecommunications market, focusing on preferences for home fixed, home mobile, and purely mobile internet connections. Central to this research is the analysis of consumer preferences for internet service attributes, including connection speed, latency, data limits, and cost. This exploration, conducted using the stated preference DCE method, reveals a nuanced perspective on how different internet services are valued by consumers.

A key finding is the moderate level of substitutability between fixed and mobile internet services. This demonstrates that while consumers view these services as partly interchangeable, they do not consider them to be perfect substitutes. This moderate substitutability plays a pivotal role in influencing consumer choice, suggesting that changes in the price or quality of one service type could moderately impact the demand for the other.

A comprehensive analysis of demand elasticity, especially regarding own- and cross-price elasticities, highlights the complexities of consumer decision-making and price sensitivity. It also emphasizes the implications for market definitions relevant to antitrust discussions and competitive agreements. Regulatory implications suggest that fixed and mobile internet services should continue to be regulated as separate markets due to their distinct characteristics and moderate substitutability. Furthermore, the study sheds light on how the unfolding advancements in telecommunications technology, especially the emergence of 5G, could reshape consumer choices and the competitive landscape in the telecommunications market. As 5G technology becomes more widespread and affordable, it may increase the substitutability of mobile internet, necessitating further research to monitor its impact on consumer behavior and market structures.

In conclusion, our study provides a comprehensive analysis of the fixed-to-mobile internet substitution in the Polish market, revealing moderate substitutability between these services as of 2018. Through detailed elasticity estimations and application of the SSNIP test, we found no grounds for merging fixed and mobile internet into a single market. Notably, the emerging 5G technology could further influence these dynamics, underscoring the need for ongoing market assessment. This research offers valuable insights for defining relevant markets and informs strategic decisions in telecommunications, highlighting the importance of adapting to technological advancements and evolving consumer preferences.

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8. Appendix.

Table 5. Own- and Cross-Elasticities for Developed and Undeveloped Areas with Baseline and 5G Scenarios

		HF	HM	MO	HF+HM	HF+MO	HM+MO	HF+HM+MO	No access	HM or MO or HM+MO	Any access	HF service (HF or HF+HM or HF+MO or HF+HM+MO)	HM service (HM or HF+HM or HM+MO or HF+HM+MO)	MO service (MO or HF+MO or HM+MO or HF+HM+MO)
Scenario C: Baseline (BSL) developed area	Elasticities in relation to HF price change (std. err.)	-0.2489***	0.4068***	0.3375***	-0.2039***	-0.1904***	0.2965***	-0.1543***	0.4088***	0.3745***	-0.0313***	-0.2361***	0.2565***	0.1198***
		(0.0076)	(0.0126)	(0.011)	(0.01)	(0.0081)	(0.013)	(0.0114)	(0.0209)	(0.0105)	(0.002)	(0.0067)	(0.0087)	(0.0053)
	Elasticities in relation to HM price change (std. err.)	0.1464***	-0.4527***	0.1818***	-0.3657***	0.1416***	-0.2895***	-0.2199***	0.1973***	-0.2369***	-0.0149***	0.0963***	-0.4082***	0.0786***
		(0.0047)	(0.0133)	(0.008)	(0.0151)	(0.0058)	(0.0125)	(0.0126)	(0.0102)	(0.0077)	(0.0009)	(0.0033)	(0.011)	(0.0044)
	Elasticities in relation to MO price change (std. err.)	0.1059***	0.1432***	-0.5076***	0.1649***	-0.4119***	-0.3727***	-0.2791***	0.1206***	-0.11***	-0.0093***	0.0412***	0.0717***	-0.4417***
		(0.0032)	(0.0056)	(0.0179)	(0.0071)	(0.0152)	(0.0162)	(0.0168)	(0.0069)	(0.0043)	(0.0006)	(0.0018)	(0.0037)	(0.0127)
	Elasticities in relation to HF+HM price change (std. err.)	-0.1442***	-0.2425***	1.0232***	-1.1582***	-0.0382***	-0.0858***	-0.7525***	1.2603***	0.1721***	-0.0938***	-0.2273***	-0.4173***	0.3963***
		(0.0081)	(0.0131)	(0.0337)	(0.0472)	(0.0087)	(0.0107)	(0.0459)	(0.051)	(0.0094)	(0.0051)	(0.0074)	(0.0132)	(0.0152)
	Elasticities in relation to HF+MO price change (std. err.)	-0.2699***	1.0151***	-0.3187***	-0.0746***	-1.0876***	-0.1498***	-0.7936***	1.0203***	0.4887***	-0.0771***	-0.3623***	0.6072***	-0.5893***
		(0.0111)	(0.0287)	(0.0179)	(0.0114)	(0.0404)	(0.0154)	(0.0437)	(0.0411)	(0.0164)	(0.0042)	(0.0109)	(0.0189)	(0.0186)
	Elasticities in relation to HM+MO price change (std. err.)	0.2589***	-0.3626***	-0.2735***	-0.2474***	-0.2215***	-0.658***	-0.5013***	0.319***	-0.3622***	-0.024***	0.1447***	-0.3794***	-0.3223***
		(0.0072)	(0.0125)	(0.0105)	(0.0117)	(0.0098)	(0.0279)	(0.0279)	(0.0148)	(0.0108)	(0.0014)	(0.0046)	(0.0111)	(0.0094)
	Elasticities in relation to HF+HM+MO price change (std. err.)	0.0284***	0.0109***	0.0411***	-0.4446***	-0.4015***	-0.404***	-0.6643***	0.7478***	-0.019***	-0.057***	-0.076***	-0.1487***	-0.216***
		(0.0037)	(0.0045)	(0.0045)	(0.0191)	(0.0158)	(0.0182)	(0.0367)	(0.0283)	(0.004)	(0.0028)	(0.0031)	(0.0057)	(0.0078)
Scenario D: Counterfactual (CFL) developed area	Elasticities in relation to HF price change (std. err.)	-0.2432***	0.3073***	0.4008***	-0.1617***	-0.1941***	0.2677***	-0.1391***	0.5058***	0.3344***	-0.0406***	-0.2296***	0.2071***	0.1471***
		(0.0069)	(0.0102)	(0.0134)	(0.0073)	(0.0078)	(0.012)	(0.0097)	(0.0244)	(0.0097)	(0.0024)	(0.0061)	(0.0073)	(0.0064)
	Elasticities in relation to HM price change (std. err.)	0.1801***	-0.5468***	0.2361***	-0.5315***	0.2019***	-0.4518***	-0.3521***	0.1391***	-0.2807***	-0.0111***	0.1238***	-0.5256***	0.1055***
		(0.0052)	(0.0184)	(0.0096)	(0.0231)	(0.0074)	(0.0203)	(0.0214)	(0.007)	(0.0092)	(0.0007)	(0.0039)	(0.0163)	(0.0057)
	Elasticities in relation to MO price change (std. err.)	0.1226***	0.1175***	-0.5479***	0.146***	-0.4264***	-0.3085***	-0.2473***	0.149***	-0.1375***	-0.012***	0.0507***	0.061***	-0.4583***
		(0.0038)	(0.0051)	(0.0187)	(0.0066)	(0.0152)	(0.0132)	(0.0153)	(0.0086)	(0.0059)	(0.0008)	(0.0023)	(0.0033)	(0.013)
	Elasticities in relation to HF+HM price change (std. err.)	-0.2916***	-0.1928***	1.3831***	-1.2691***	-0.1227***	-0.1206***	-0.9242***	1.5696***	0.3323***	-0.1227***	-0.3505***	-0.3932***	0.5427***
		(0.0125)	(0.0114)	(0.0433)	(0.053)	(0.0129)	(0.0129)	(0.0582)	(0.0588)	(0.0133)	(0.0063)	(0.0111)	(0.0141)	(0.0211)

	Elasticities in relation to HF+MO	-0.2988***	1.0256***	-0.3717***	-0.0373***	-1.475***	-0.1062***	-0.9229***	1.6719***	0.4702***	-0.1326***	-0.4354***	0.6484***	-0.7521***
	price change (std. err.)	(0.0125)	(0.0331)	(0.0226)	(0.0116)	(0.0518)	(0.0162)	(0.0511)	(0.0612)	(0.0165)	(0.0065)	(0.0126)	(0.0218)	(0.0235)
	Elasticities in relation to HM+MO	0.3032***	-0.3242***	-0.4704***	-0.2731***	-0.3405***	-0.7536***	-0.6025***	0.3012***	-0.4099***	-0.0237***	0.1686***	-0.3729***	-0.4681***
	price change (std. err.)	(0.0078)	(0.0114)	(0.0185)	(0.0133)	(0.0146)	(0.0326)	(0.0334)	(0.0143)	(0.0124)	(0.0014)	(0.005)	(0.0119)	(0.0136)
	Elasticities in relation to	0.0071**	0.043***	0.0194***	-0.4378***	-0.5334***	-0.4169***	-0.7307***	0.8835***	-0.0055	-0.0706***	-0.1033***	-0.1175***	-0.2694***
	HF+HM+MO price change (std. err.)	(0.0048)	(0.0032)	(0.0065)	(0.0187)	(0.0204)	(0.0187)	(0.0403)	(0.0317)	(0.0036)	(0.0034)	(0.0041)	(0.0051)	(0.0094)
Scenario E: Baseline (BSL) undeveloped area	**Elasticities in relation to HF price**		-0.2281***	0.3025***			-0.1584***		0.3115***	-0.0574***	-0.0574***			
	change (std. err.)		(0.0067)	(0.0093)			(0.0073)		(0.0135)	(0.0029)	(0.0029)			
	Elasticities in relation to MO price		0.2047***	-0.4084***			-0.3282***		0.1629***	-0.0299***	-0.0299***			
	change (std. err.)		(0.006)	(0.0124)			(0.0138)		(0.0073)	(0.0017)	(0.0017)			
	Elasticities in relation to HF+MO		-0.0644***	-0.0431***			-0.4717***		0.4988***	-0.0925***	-0.0925***			
	price change (std. err.)		(0.0047)	(0.0044)			(0.0183)		(0.0188)	(0.0042)	(0.0042)			
Scenario F: Counterfactual (CFL) undeveloped area	**Elasticities in relation to HF price**		-0.3494***	0.487***			-0.274***		0.3788***	-0.0742***	-0.0742***			
	change (std. err.)		(0.0106)	(0.0143)			(0.0133)		(0.0141)	(0.0036)	(0.0036)			
	Elasticities in relation to MO price		0.1976***	-0.4537***			-0.2866***		0.2553***	-0.05***	-0.05***			
	change (std. err.)		(0.0063)	(0.0129)			(0.0121)		(0.0108)	(0.0024)	(0.0024)			
	Elasticities in relation to HF+MO		-0.0593***	-0.1311***			-0.5796***		0.6292***	-0.1244***	-0.1244***			
	price change (std. err.)		(0.0049)	(0.0073)			(0.0227)		(0.0211)	(0.0052)	(0.0052)			

Note 1: The internet characteristics for the BSL scenario are 600 Mb/s (speed), 10 ms (latency), unlimited transfer limit with cost of 60 PLN/month for HF alternative; 90 Mb/s, 30 ms, 70 Gb transfer limit with cost of 50 PLN/month for HM; and 30 Mb/s, 30 ms, 70 Gb transfer limit with cost of 60 PLN/month for MO. For the CFL scenario, the HM alternative was replaced by the HM5G alternative with 600 Mb/s (speed), 20 ms (latency), 150 Gb transfer limit with a cost of 85 PLN/month. The aforementioned attribute values were artificially selected to reflect the actual value of internet connection characteristics available on the Polish market in developed and underdeveloped areas.

Note 2: Significance levels: * p <0.1, ** p <0.05, *** p <0.01

9. Online Supplement

9.1. Econometric framework

For modelling choices and to recover estimates of willingness to pay for changes in each attribute, we base our approach on random utility theory (McFadden, 1974). In this model, the utility of the individual i resulting from choosing alternative j in situation t can be expressed as:

$$V_{ijt} = ac_{ijt} + \mathbf{bX}_{ijt} + e_{ijt} , \tag{2}$$

where the utility expression is assumed additively separable in the cost of the alternative, c_{ijt}, and other attributes, $\mathbf{X}_{ijt}$; a and $\mathbf{b}$ denote the corresponding parameters; and e_{ijt} is a stochastic component allowing for factors not observed by the econometrician to affect individuals' utility and choices. The researcher does not observe e_{ijt}, however, they are able to assume its distribution. Depending on this assumption, the model can be transformed into different classes of choice models. Assuming that the stochastic component e_{ijt} follows an independent and identically distributed extreme value (type I) distribution, it leads to the logit probability specification, used in simple conditional logistic regressions, with a probability of choosing alternative j from a set of J available alternatives:

$$P_{ijt}\left(a,\mathbf{b}\right) = \frac{\exp\left(ac_{ijt} + \mathbf{bX}_{ijt}\right)}{\sum_{k=1}^{J}\exp\left(ac_{ikt} + \mathbf{bX}_{ikt}\right)} . \tag{3}$$

Given that we are interested in deriving willingness to pay values from choices, based on respondents willingness to trade off increases in any of the biodiversity attributes against increases in the monetary attribute c_{ijt}, it is convenient to introduce the following modification of (2), which is equivalent to using a money-metric utility function (in our case, it means estimating the parameters in WTP space; Scarpa et al., 2008; Train and Weeks, 2005):

$$U_{ijt} = \sigma a\left(c_{ijt} + \sigma \mathbf{b} X_{ijt}\right) + \varepsilon_{ijt} = \lambda\left(c_{ijt} + \boldsymbol{\beta} X_{ijt}\right) + \varepsilon_{ijt} \tag{4}$$

In this specification, by rescaling the utility function, the vector of parameters, $\boldsymbol{\beta} = \mathbf{b}/a$ can be directly interpreted as a vector of the implicit prices (marginal WTPs) for the non-monetary attributes, $\mathbf{X}_{ijt}$, facilitating an interpretation of the results.

An inconvenient assumption of this simple (multinomial logit) model is the independence and identical distribution of the error term for all of the alternatives and respondents, as well as identical preferences of different respondents – the same coefficients λ and $\boldsymbol{\beta}$ in the utility function for all individuals. One way of relaxing this assumption – that is, allowing for some level of (unobserved) preference heterogeneity and, possibly, correlations between the alternatives and choice tasks – is to is to include consumer-specific parameters, λ_i, $\boldsymbol{\beta}_i$, which leads to a Mixed Logit Model (MXL). A commonly used approach is to make mixing distributions continuous. If individual parameters are assumed continuously distributed following a parametric distribution specified *a priori* by a modeler, $[\lambda_i, \boldsymbol{\beta}_i] \sim f\left(\bar{\boldsymbol{\beta}}, \boldsymbol{\Sigma}\right)$, with means, $\bar{\boldsymbol{\beta}}$, and variance-covariance matrix, $\boldsymbol{\Sigma}$, the random parameters mixed logit model is formed (RP-MXL, Hensher and Greene, 2003). In RP-MXL, the probability of making given choices in a set of T situations, is a weighted average of standard logit probabilities and it can be presented as:

$$P_i(\theta) = \int \left(\prod_t \sum_j I_{ijt} P_{ijt}\left([\lambda, \boldsymbol{\beta}]\right) \right) f\left([\lambda, \boldsymbol{\beta}] \mid \theta\right) d[\lambda, \boldsymbol{\beta}], \tag{5}$$

where I_{ijt} equals 1 if individual i has chosen alternative j, and it equals 0 otherwise. The utility function for respondents is analogical to an MNL model, except for the fact that the vector of the parameters $[\lambda_i, \boldsymbol{\beta}_i]$ can vary for different respondents.

The model is estimated using the maximum likelihood method for the utility function parameters, conditional on individuals' observed choices and attribute levels associated with choice alternatives. Estimating the RP-MXL model requires the use of simulation methods because the integral in (5) does not have a closed form. We can thus apply a simulation procedure in which $[\lambda_r, \boldsymbol{\beta}_r]$ is drawn from $f([\lambda_r, \boldsymbol{\beta}_r] | \theta)$ and, for each $[\lambda_r, \boldsymbol{\beta}_r]$ the logit formula is calculated. The simulated probability is given by the average over R draws:

$$\hat{P}_i(\theta) = \frac{1}{R} \sum_{r=1}^{R} \left(\prod_t \sum_j I_{ijt} P_{ijt}\left([\lambda_r, \boldsymbol{\beta}_r]\right) \right). \quad (6)$$

$\hat{P}_i(\theta)$ is an unbiased estimator of $P_i(\theta)$ by construction. The simulated probabilities can then be used in a log-likelihood function (McFadden and Train, 2000). In the simulation, we used 10,000 scrambled Sobol draws (Czajkowski and Budziński, 2019).

The elasticity analysis concerns the examination of how the probability of choosing a specific internet alternative (a single service or a combination of services) changes in response to a variation in its price. Importantly, our calculations account for the fact that increasing the cost of one of these three basic services (HF, HM or MO) also impacts the prices of combinations involving that service. For instance, raising the price of HF inadvertently increases the price of the HF+HM, HF+MO, and HF+HM+MO packages too. Following Train (2009), the formula for the elasticity of the probability of choosing the alternative i (P_i) with respect to the attribute j (x_{ij}) can be written as:

$$\varepsilon_{ij} = \frac{\partial P_i}{\partial x_{ij}} \times \frac{x_{ij}}{P_i} \quad (7)$$

This formula can be further transformed into the arc elasticity formula (also known as the midpoint elasticity formula), which provides a more stable measure when changes in attributes are not infinitesimally small. The arc elasticity formula can be simplified to:

$$\varepsilon_i = \frac{\Delta P_i}{\Delta Cost_i} \times \frac{\overline{Cost_i}}{\bar{P_i}} \quad (8),$$

where $\Delta P_i = P_{i,1} - P_{i,0}$ represents the changes in probabilities (the difference between $P_{i,1}$ – the probability of choosing a specific alternative after the cost j was increased – and $P_{i,1}$ – the probability of choosing a specific alternative before the cost j was increased). Similarly, $\Delta Cost_i = Cost_{i,1} - Cost_{i,0}$ represents the change in costs. Conversely, $\overline{Cost}$ and $\bar{P}$ represents the means (midpoints) of cost ($Cost_{i,1}$ and $Cost_{0,1}$) and the probability of choosing the specific alternative ($P_{i,1}$ and $P_{0,1}$), respectively.

It is also worth noting that our calculations were based on a mixed logit model with correlated random parameters, which necessitated the use of appropriate transformations and simulations in order to calculate the probabilities from the formula (6).

9.2. Own- and cross-elasticities estimated for median characteristics values

Table 3 extended. Own- and cross-elasticities estimated for median characteristics values

	HF	HM	MO	HF+HM	HF+MO	HM+MO	HF+HM+MO	No access	HM or MO or HM+MO	Any access	HF service (HF or HF+HM or HF+MO or HF+HM+MO)	HM service (HM or HF+HM or HM+MO or HF+HM+MO)	MO service (MO or HF+MO or HM+MO or HF+HM+MO)
Elasticities in relation to HF price change (std. err.)	-0.1971*** (0.006)	0.3337*** (0.0104)	0.2072*** (0.0072)	-0.1771*** (0.0075)	-0.1296*** (0.0054)	0.2094*** (0.0094)	-0.1143*** (0.0069)	0.3189*** (0.0158)	0.2877*** (0.0084)	-0.0276*** (0.0017)	-0.1843*** (0.0053)	0.2095*** (0.0071)	0.0829*** (0.0033)
Elasticities in relation to HM price change (std. err.)	0.1351*** (0.0043)	-0.369*** (0.0111)	0.1184*** (0.0049)	-0.3623*** (0.0145)	0.1247*** (0.0051)	-0.2239*** (0.0095)	-0.1937*** (0.0113)	0.1251*** (0.0066)	-0.2151*** (0.0072)	-0.0106*** (0.0007)	0.0879*** (0.003)	-0.3364*** (0.0093)	0.0639*** (0.0029)
Elasticities in relation to MO price change (std. err.)	0.0989*** (0.0028)	0.1202*** (0.0039)	-0.4943*** (0.0178)	0.1872*** (0.007)	-0.5323*** (0.0212)	-0.4704*** (0.0202)	-0.3903*** (0.0244)	0.0853*** (0.0045)	-0.0988*** (0.0036)	-0.0073*** (0.0005)	0.0443*** (0.0015)	0.0743*** (0.003)	-0.467*** (0.0148)
Elasticities in relation to HF+HM price change (std. err.)	-0.1452*** (0.0093)	-0.1719*** (0.0098)	0.8945*** (0.0303)	-1.3667*** (0.0507)	-0.0154 (0.0091)	-0.0357*** (0.0098)	-0.7863*** (0.0474)	1.3537*** (0.0584)	0.1472*** (0.0085)	-0.1217*** (0.0064)	-0.2356*** (0.0086)	-0.3799*** (0.0133)	0.4001*** (0.0138)
Elasticities in relation to HF+MO price change (std. err.)	-0.3795*** (0.0141)	1.0831*** (0.0301)	-0.2337*** (0.0126)	-0.188*** (0.018)	-1.1205*** (0.043)	-0.1756*** (0.0158)	-0.8853*** (0.0508)	1.0091*** (0.0431)	0.6199*** (0.0204)	-0.0893*** (0.005)	-0.425*** (0.0129)	0.6743*** (0.02)	-0.4971*** (0.0179)
Elasticities in relation to HM+MO price change (std. err.)	0.2676*** (0.0072)	-0.4148*** (0.0136)	-0.2332*** (0.0094)	-0.3539*** (0.0173)	-0.243*** (0.0114)	-0.6652*** (0.0274)	-0.5646*** (0.0314)	0.2381*** (0.0112)	-0.3856*** (0.0116)	-0.0204*** (0.0012)	0.1583*** (0.0048)	-0.4059*** (0.0119)	-0.2803*** (0.0094)
Elasticities in relation to HF+HM+MO price change (std. err.)	0.0069** (0.0045)	0.0133*** (0.0045)	0.0448*** (0.0033)	-0.5155*** (0.0214)	-0.3769*** (0.0152)	-0.354*** (0.0157)	-0.6456*** (0.0359)	0.6975*** (0.0281)	-0.0098** (0.0036)	-0.0636*** (0.0033)	-0.0764*** (0.0039)	-0.1231*** (0.0057)	-0.1531*** (0.0064)

Note 1: The median of respondents' internet characteristics (presented in Table 8 in the online supplement) are 50 Mb/s (speed), 50 ms (latency), unlimited transfer limit with cost of 40 PLN/month for HF alternative; 30 Mb/s, 100 ms, 20 Gb transfer limit with cost of 40 PLN/month for HM; and 20 Mb/s, 100 ms, 10 Gb transfer limit with cost of 75 PLN/month for MO.

Note 2: Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

9.3. Own- and Cross-Elasticities with Baseline and 5G Scenarios

Table 4 extended. Own- and Cross-Elasticities with Baseline and 5G Scenarios

		HF	HM	MO	HF+HM	HF+MO	HM+MO	HF+HM+MO	No access	HM or MO or HM+MO	Any access	HF service (HF or HF+HM or HF+MO or HF+HM+MO)	HM service (HM or HF+HM or HM+MO or HF+HM+MO)	MO service (MO or HF+MO or HM+MO or HF+HM+MO)
Scenario A: Baseline (BSL)	Elasticities in relation to HF price change (std. err.)	-0.2706*** (0.0084)	0.4276*** (0.0131)	0.3564*** (0.0114)	-0.2245*** (0.0111)	-0.2099*** (0.009)	0.3141*** (0.0136)	-0.1689*** (0.0125)	0.4049*** (0.0204)	0.3946*** (0.0109)	-0.0319*** (0.0021)	-0.2534*** (0.0074)	0.2805*** (0.0092)	0.1387*** (0.0056)
	Elasticities in relation to HM price change (std. err.)	0.1481*** (0.0046)	-0.4747*** (0.0143)	0.1891*** (0.0084)	-0.3946*** (0.0164)	0.1478*** (0.0059)	-0.3161*** (0.0138)	-0.24*** (0.0139)	0.1824*** (0.0091)	-0.2427*** (0.0079)	-0.014*** (0.0008)	0.1025*** (0.0034)	-0.4193*** (0.0117)	0.0965*** (0.0047)
	Elasticities in relation to MO price change (std. err.)	0.1063*** (0.0031)	0.1431*** (0.0054)	-0.5206*** (0.0184)	0.1703*** (0.0071)	-0.4363*** (0.0162)	-0.3948*** (0.0171)	-0.2985*** (0.0182)	0.1152*** (0.0065)	-0.1096*** (0.0043)	-0.0089*** (0.0006)	0.0473*** (0.0018)	0.0858*** (0.0038)	-0.4401*** (0.0129)
	Elasticities in relation to HF+HM price change (std. err.)	-0.1676*** (0.0085)	-0.2714*** (0.0139)	1.0842*** (0.0348)	-1.1675*** (0.0479)	-0.0566*** (0.0093)	-0.1063*** (0.0115)	-0.7755*** (0.0477)	1.2615*** (0.0473)	0.1879*** (0.0097)	-0.0991*** (0.0051)	-0.2291*** (0.0077)	-0.3987*** (0.0131)	0.4754*** (0.0169)
	Elasticities in relation to HF+MO price change (std. err.)	-0.2977*** (0.0119)	1.0412*** (0.0284)	-0.3413*** (0.0184)	-0.0991*** (0.0122)	-1.1036*** (0.0417)	-0.1761*** (0.0163)	-0.8149*** (0.0451)	0.9838*** (0.0389)	0.5119*** (0.017)	-0.0775*** (0.0043)	-0.3676*** (0.0115)	0.6675*** (0.0194)	-0.5522*** (0.018)
	Elasticities in relation to HM+MO price change (std. err.)	0.2658*** (0.0072)	-0.3838*** (0.013)	-0.2954*** (0.0113)	-0.2717*** (0.0128)	-0.2446*** (0.0107)	-0.6838*** (0.0291)	-0.5313*** (0.0295)	0.3081*** (0.0145)	-0.3833*** (0.0114)	-0.0237*** (0.0014)	0.1594*** (0.0048)	-0.3748*** (0.0113)	-0.3102*** (0.0095)
	Elasticities in relation to HF+HM+MO price change (std. err.)	0.0228*** (0.0039)	0.0041 (0.0047)	0.0358*** (0.0049)	-0.4685*** (0.0201)	-0.4265*** (0.0168)	-0.4285*** (0.0192)	-0.6947*** (0.0384)	0.7857*** (0.0283)	-0.0257*** (0.0042)	-0.0638*** (0.0031)	-0.0687*** (0.0034)	-0.1253*** (0.0055)	-0.1854*** (0.0073)
Scenario B: Counterfactual (CFL)	Elasticities in relation to HF price change (std. err.)	-0.269*** (0.0077)	0.3316*** (0.0109)	0.4274*** (0.014)	-0.178*** (0.0081)	-0.2154*** (0.0087)	0.2858*** (0.0127)	-0.1522*** (0.0106)	0.5101*** (0.0243)	0.3591*** (0.0103)	-0.0425*** (0.0026)	-0.2508*** (0.0069)	0.2319*** (0.0079)	0.1683*** (0.0069)
	Elasticities in relation to HM price change (std. err.)	0.1778*** (0.005)	-0.5575*** (0.0191)	0.236*** (0.0095)	-0.5517*** (0.024)	0.2029*** (0.0073)	-0.4709*** (0.0211)	-0.3693*** (0.0225)	0.1332*** (0.0067)	-0.2819*** (0.0092)	-0.0107*** (0.0007)	0.1292*** (0.0039)	-0.5216*** (0.0165)	0.1252*** (0.0058)

Elasticities in relation to MO price change (std. err.)	0.1225*** (0.0037)	0.1206*** (0.0052)	-0.5647*** (0.0196)	0.1525*** (0.0068)	-0.4525*** (0.0162)	-0.3301*** (0.0142)	-0.2654*** (0.0166)	0.1414*** (0.008)	-0.1362*** (0.0058)	-0.0115*** (0.0008)	0.0551*** (0.0023)	0.0745*** (0.0036)	-0.4629*** (0.0134)
Elasticities in relation to HF+HM price change (std. err.)	-0.3181*** (0.0129)	-0.212*** (0.0122)	1.4338*** (0.0434)	-1.2777*** (0.0538)	-0.1461*** (0.0138)	-0.1377*** (0.0136)	-0.9442*** (0.0596)	1.5414*** (0.055)	0.3547*** (0.0142)	-0.1268*** (0.0063)	-0.3552*** (0.0115)	-0.363*** (0.0133)	0.6256*** (0.0224)
Elasticities in relation to HF+MO price change (std. err.)	-0.3388*** (0.0134)	1.0719*** (0.0337)	-0.41*** (0.0237)	-0.0573*** (0.0121)	-1.4882*** (0.0533)	-0.1306*** (0.0169)	-0.9447*** (0.0529)	1.6412*** (0.0577)	0.4978*** (0.0173)	-0.1375*** (0.0065)	-0.4477*** (0.0134)	0.7247*** (0.0234)	-0.7172*** (0.0231)
Elasticities in relation to HM+MO price change (std. err.)	0.3046*** (0.0077)	-0.3392*** (0.0121)	-0.4821*** (0.0188)	-0.2926*** (0.0142)	-0.3633*** (0.0156)	-0.7752*** (0.0336)	-0.6277*** (0.0346)	0.2903*** (0.0138)	-0.4236*** (0.0129)	-0.0232*** (0.0014)	0.1807*** (0.0051)	-0.3601*** (0.0118)	-0.4496*** (0.0137)
Elasticities in relation to HF+HM+MO price change (std. err.)	0.0024 (0.0055)	0.039*** (0.0032)	0.0095* (0.0066)	-0.4645*** (0.0202)	-0.5621*** (0.0222)	-0.4339*** (0.019)	-0.7319*** (0.0456)	0.8962*** (0.0309)	-0.0114*** (0.0038)	-0.0766*** (0.0038)	-0.0957*** (0.0046)	-0.0904*** (0.0043)	-0.2418*** (0.0089)

Note 1: The internet characteristics for the BSL scenario are 600 Mb/s (speed), 10 ms (latency), unlimited transfer limit with cost of 60 PLN/month for HF alternative; 90 Mb/s, 30 ms, 70 Gb transfer limit with cost of 50 PLN/month for HM; and 30 Mb/s, 30 ms, 70 Gb transfer limit with cost of 60 PLN/month for MO. For the CFL scenario, the HM alternative was replaced by the HM5G alternative with 600 Mb/s (speed), 20 ms (latency), 150 Gb transfer limit with a cost of 85 PLN/month. The aforementioned attribute values were artificially selected to reflect the actual value of internet connection characteristics available on the Polish market in developed and underdeveloped areas.

Note 2: Significance levels: * p <0.1, ** p <0.05, *** p <0.01

9.4. Random parameters logit model estimates in preference space

Table 6. Random parameters logit model estimates in preference space

		Means			Standard Deviations		
	Distribution	Coef.		Std. error	Coef.		Std. error
HF	Normal	-0.9084	***	0.3202	6.2798	***	0.2464
HM	Normal	-4.7020	***	0.3925	6.1320	***	0.2592
MO	Normal	-5.1935	***	0.3871	6.2528	***	0.2549
HF+HM	Normal	-6.0268	***	0.3988	6.7887	***	0.2640
HF+MO	Normal	-5.6645	***	0.3952	6.8987	***	0.2618
HM+MO	Normal	-7.0785	***	0.4041	6.9459	***	0.2598
HF+HM+MO	Normal	-8.2224	***	0.4247	7.4526	***	0.2734
log(Speed (Gb/s))	Normal	0.1718	***	0.0056	0.1881	***	0.0071
-log(Latency (100 ms))	Log-Normal	0.0331	***	0.3382	0.0431	***	0.1165
log(Transfer (100 GB))	Log-Normal	0.0815	***	0.0808	0.0473	***	0.0284
-Cost (100 PLN)	Log-Normal	1.5078	***	0.0395	2.4430	***	0.0276
Log-likelihood		-85,795.15					
McFadden's pseudo-R^2		0.1475					
Ben-Akiva-Lerman's pseudo-R^2		0.2859					
AIC/n		2.7502					
BIC/n		2.7613					
Observations (n)		62,448					
Respondents		5,204					
Parameters		77					
Number of Sobol draws		10,000					

Note: Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

9.5. Summary statistics on key demographics from the sample

Table 7. Descriptive statistics – demographics

Variable	n	Levels	Share
Sex	5204	Male	47.9%
		Female	52.1%
Age	5204	18-20	4.6%
		21-30	18.5%
		31-40	20.7%
		41-50	16.0%
		51-60	15.4%
		61+	24.8%
Education	5204	Primary or secondary education	6.6%
		Basic or vocational education	28.7%
		Secondary vocational, general secondary or post-secondary education	37.2%
		Higher education (Bachelor's degree, Engineer's degree, Master's degree, PhD)	27.5%
Region (voivodeship)	5204	Dolnośląskie	7.8%
		Kujawsko-pomorskie	5.5%
		Lubelskie	6.2%
		Lubuskie	2.8%
		Łódzkie	6.1%
		Małopolskie	8.7%
		Mazowieckie	13.8%
		Opolskie	2.6%
		Podkarpackie	5.5%
		Podlaskie	3.0%
		Pomorskie	5.7%
		Śląskie	12.3%
		Świętokrzyskie	3.1%
		Warmińso-mazurskie	4.0%
		Wielkopolskie	9.0%
		Zachodniopomorskie	4.0%
City size	5204	Country side	36.0%
		City with up do 3 000 inhabitants	2.9%
		City with between 3 001 and 10 000 inhabitants	5.3%
		City with between 10 001 and 50 000 inhabitants	16.2%
		City with between 50 001 and 100 000 inhabitants	10.6%
		City with between 100 001 and 200 000 inhabitants	8.3%

Variable	n	Levels	Share
Devices connected to the Internet in the household	5204	Mobile phone	94.8%
		Laptop / Notebook / Ultrabook	80.6%
		TV	47.3%
		PC	45.8%
		Tablet	42.4%
		Watch	5.4%
		Other (e.g., console)	2.6%
Types of internet access used in the household	5204	Home internet (HF or HM)	95.8%
		Home Fixed internet (HF)	72.0%
		Home Mobile internet (HM)	70.3%
		Mobile internet (MO)	94.4%
Types of HF access	3749	Telephone line	33.4%
		Cable TV network	34.8%
		Local line	13.4%
		Fibre (FTTH)	14.8%
		Other	1.4%
		I don't know, it's hard to say	2.2%
Types of HM access	3656	Dedicated device connected to electricity	61.6%
		Device connected to a computer/laptop via USB	14.4%
		An additional SIM card inserted into a laptop/tablet	18.4%
		Other	1.4%
		I don't know, it's hard to say	4.3%
Using HM internet outside the home	3656	No	33.1%
		I don't know, it's hard to say	1.5%
		Yes	65.3%
Frequency of using HM internet outside the home	2389	Every day or almost every day	51.5%
		Several times a week	16.5%
		Several times a month	15.7%
		Several times a year	14.5%
		I don't know, it's hard to say	1.8%
Using MO - tethering	4910	No	42.8%
		I don't know, it's hard to say	10.3%
		Yes	46.9%
Frequency of using tethering	2303	Every day or almost every day	26.9%

		City with over 200 00 inhabitants	20.6%
Hosehold size	5204	1	10.2%
		2	28.0%
		3	25.7%
		4	19.9%
		5	9.7%
		6	4.0%
		7	1.6%
		8 or more	0.9%
Net household income	5204	Less than 1 000 PLN	2.9%
		1 000 - 1 999 PLN	7.6%
		2 000 - 2 999 PLN	13.6%
		3 000 - 3 999 PLN	15.0%
		4 000 - 4 999 PLN	10.5%
		5 000 - 7 499 PLN	21.7%
		7 500 - 9 999 PLN	8.1%
		10 000 - 19 999 PLN	3.8%
		Over 20 000 PLN	0.6%
		I don't kow	3.0%
		I don't want to answer	13.3%

		Several times a week	20.1%
		Several times a month	27.6%
		Several times a year	19.1%
		I don't know, it's hard to say	6.3%
Frequency of using HF, HM or MO internet	5204	Every day	93.5%
		Several times a week	4.6%
		About once a week or less	1.5%
		I don't know, it's hard to say	0.4%
Total time spent on the internet per week	4876	Up to 10 hours	21.4%
		Between 10 and 30 hours	48.4%
		Between 30 and 50 hours	2.4%
		Between 50 and 70 hours	20.8%
		70 hours or more	7.0%
Types of internet usage	5204	e-mail	96.8%
		internet banking, official matters	85.9%
		online shopping/selling	83.1%
		internet portals	82.5%
		social networking sites	81.0%
		programs, applications (e.g., maps, navigation)	65.3%
		listening to the ratio (or music) via the internet	48.4%
		video services (VOD), watching movies	47.6%
		online games	35.2%
		file transfer	34.3%
		E-administration	21.2%

Table 8. Descriptive statistics – internet usage and respondents' current internet access characteristics

Maximum link speed	HF	HM	MO
n	3749	3654	4910
1 Gb/s or more	3.7%	2.9%	2.8%
200 - 999 Mb/s	7.7%	4.8%	3.6%
100 - 199 Mb/s	19.4%	12.9%	10.0%
30 - 99 Mb/s	26.4%	23.5%	17.4%
10 - 29 Mb/s	22.3%	21.0%	19.8%
2 - 9 Mb/s	7.8%	13.8%	15.2%
2 Mb/s or less	0.9%	2.4%	4.8%
I don't know, it's hard to say	11.8%	18.7%	26.4%

Maximum latency	HF	HM	MO
n	3749	3654	4910
15 ms - online games run smoothly in real time	25.2%	13.6%	11.5%
50 ms - internet telephony services work smoothly	15.7%	17.4%	19.4%
100 ms - websites and music/video services work smoothly	14.2%	16.8%	15.8%
250 ms - music/video services work smoothly	5.9%	8.5%	8.1%
500 ms - some websites load slowly	11.7%	14.0%	11.2%
Other	0.7%	0.6%	0.4%
I don't know, it's hard to say	26.5%	29.1%	33.6%

Transfer limit (for mobile access)	HF	HM	MO
n		3343	4058
No limit		9.5%	8.1%
More than 100 GB		3.2%	2.8%
50 - 100 GB		19.6%	3.4%
21 - 50 GB		17.2%	7.9%
11 - 20 GB		14.1%	16.0%
6 - 10 GB		16.1%	24.1%
2 -5 GB		8.9%	19.1%
1 - 2 GB		2.5%	8.6%
Less than 1 GB		0.4%	1.4%
I don't know, it's hard to say		8.4%	8.2%

Cost of home internet	HF	HM	MO
n	2749	3656	
More than 101 PLN/month	6.3%	6.6%	
51 - 100 PLN/month	30.4%	23.3%	
31 - 50 PLN/month	43.5%	34.6%	
21 - 30 PLN/month	14.1%	19.8%	
Less than 20 PLN/month	3.5%	10.7%	
I don't know, it's hard to say	2.2%	5.0%	

Cost of internet access in mobile phones	HF	HM	MO
n			4910
Less than 5 PLN/month			3.9%
5 - 9 PLN/month			10.1%
10 - 29 PLN/month			26.8%
30 - 49 PLN/month			14.8%
More than 50 PLN/month			14.2%
I don't know, it's hard to say			12.0%
It is impossible to estimate the cost of the internet itself			18.2%

Respondents' current internet access characteristics (median)	HF	HM	MO
Link speed (Mb/s)	50	30	20
Latency (ms)	50	100	100
Transfer limit (GB)	unlimited	20	10
Monthly gross cost in PLN (includes activation fees and fees for devices necessary to provide the service)	40	40	75

Respondents' current internet access characteristics (mean)	HF	HM	MO
Link speed (Mb/s)	92.82	65.85	67.85
Latency (ms)	95.16	133.52	135.15
Transfer limit (GB)	unlimited	52.11	47.6
Monthly gross cost in PLN (includes activation fees and fees for devices necessary to provide the service)	48.13	44.15	74.62

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