A Productivity Analysis and Strategic Implications of Türkiye's 5G Deployment

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ABSTRACT

This study examines the economic impact of broadband mobile network transitions on operators in Türkiye, with a specific focus on drawing evidence-based lessons from LTE to inform the strategic and financial planning for the upcoming 5G deployment. It aims to quantitatively assess the relationship between infrastructure investment, operator efficiency, and macroeconomic constraints to formulate actionable policy recommendations. The research employs a historical panel dataset of Turkish mobile network operators (MNOs) to calculate and analyze the investment efficiency ratio. The analysis reveals two critical patterns. First, LTE deployment generated significant efficiency gains, with operator capital productivity increasing by approximately 30% post-implementation. Second, this productivity is highly sensitive to financing costs. High domestic interest rates exert strong downward pressure on investment efficiency. Consequently, while 5G holds similar potential for productivity gains, its financial viability is severely challenged under current macroeconomic conditions. This paper provides a novel, integrated analysis that combines quantitative operator-level efficiency metrics with Türkiye's specific policy ambitions for technological sovereignty. It uniquely quantifies the financial friction caused by high interest rates on telecom investments and proposes a holistic policy framework.

Keywords: *5G Deployment, Investment Efficiency, Telecommunications Policy, Spectrum Auction*

JEL Classification Codes: *L96, O33, G31*

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Türkiye'nin 5G Yayılımının Verimlilik Analizi ve Stratejik Çıkarımları

ÖZET

Bu çalışma, Türkiye'deki geniş bant mobil ağ geçişlerinin operatörlere iktisadi etkisini incelemekte ve özellikle LTE'den çıkarılan kanıta dayalı dersleri, yaklaşan 5G yayılımı için stratejik ve finansal planlamaya bilgi sağlamak üzere kullanmayı hedeflemektedir. Altyapı yatırımı, operatör verimliliği ve makroekonomik kısıtlar arasındaki ilişkiyi nicel olarak değerlendirerek uygulanabilir politika önerileri formüle etmeyi amaçlamaktadır. Araştırma, yatırım verimlilik oranını hesaplamak ve analiz etmek için Türkiye'deki mobil şebeke operatörlerine ait geçmiş panel veri setini kullanmaktadır. Analiz, iki kritik örüntüyü ortaya koymaktadır. İlk olarak, LTE yayılımı, operatör sermaye verimliliğinin uygulama sonrasında yaklaşık %30 artmasıyla önemli bir verimlilik kazancı sağlamıştır. İkinci olarak, bu verimlilik finansman maliyetlerine karşı oldukça hassastır. Yüksek yerel faiz oranları, yatırım verimliliği üzerinde güçlü bir baskı oluşturmaktadır. Sonuç olarak, 5G benzer verimlilik kazançları potansiyeli taşısa da finansal fizibilitesi mevcut makroekonomik koşullar altında ciddi şekilde zorlanmaktadır. Bu makale, nicel operatör düzeyindeki verimlilik ölçütlerini Türkiye›nin teknolojik egemenliğe yönelik özel politika hedefleriyle birleştiren yeni ve bütünleşik bir analiz sunmaktadır. Telekom yatırımları üzerindeki yüksek faiz oranlarının neden olduğu finansal baskıyı ölçmekte ve bütüncül bir politika çerçevesi önermektedir.

Anahtar Kelimeler: *5G Yayılımı, Yatırım Verimliliği, Telekomünikasyon Politikası, Spektrum İhalesi.*

JEL Kodları: *L96, O33, G31*

INTRODUCTION

The telecommunications sector has long served as the backbone of economic development, technological innovation, and societal progress globally. As the digital economy rapidly accelerates, the deployment of advanced wireless technologies such as 5G marks a pivotal juncture (Parcu et al., 2023; Vu et al. 2020). Since 5G offers ultra-low latency with enormous bandwidth opportunities and very high reliability, apart from previous generations, this technology was expected to boost a wide range of novel industry verticals and create additional job openings all over the world. However, the actual outcomes, especially for mobile operators, show that they are far below expectations (Weissberger, 2023). In addition, the high charges given for 5G licenses also impose additional financial burdens on operators. Since the spectrum license auctions are one of the major income resources of governments; 5G deployments forces cellular operators to invest extensive costs on new infrastructures (Whalley and Curwen, 2024).

Community pressure is likewise a major factor on regulatory bodies and network operators for investment decisions. Since, it is uncertain whether there is a quick financial return for the mobile operators from deploying 5G networks, the auction and deployment process for 5G spectrum grants prospects to overcome the digital divide (Rastogi, 2022). The auction of 5G spectrum is a structured and regulated process through which governments allocate valuable radio frequency bands to telecommunication operators. This process is essential for fostering innovation, competition, and economic growth while ensuring efficient utilization of spectrum resources. By auctioning 5G spectrum, governments can promote innovation, economic growth, and technological advancement by enabling faster, more reliable, and efficient communication services. These auctions generate significant revenue for governments, which can be reinvested in infrastructure development or other public initiatives (Mendanço et al., 2022).

National authorities accomplish 5G spectrum auctions considering some specific goals such as efficient spectrum use, equitable access and wider penetration in coverage and population. While regulatory bodies intend to confirm efficient spectrum utilization, they also promote reasonable and fair utilization of domestic spectrum sources. Additionally, higher population coverage can be stated as a priority, with access to spectrum for private networks in beyond 5G vertical industries which is a novel concept in telecom sector (Bichler & Goeree, 2017).

Türkiye, with its strategic geopolitical position and burgeoning digital agenda, aims to position itself as a technology provider in this ecosystem. The upcoming 5G deployment in 2026 represents a critical milestone, with the potential to transform domestic connectivity infrastructure and influence the regional competitive balance. Historically, broadband deployments worldwide have predominantly prioritized maximizing government revenues and broadening network coverage. However, recent shifts in policy paradigms, especially highlighted by leading economies, currently emphasize fostering local industry growth alongside efficient spectrum utilization (Papadias et al., 2020).

Türkiye's regulatory authorities are adopting a strategic approach, with a pronounced focus on promoting indigenous technology development and local manufacturing capacities (UAB, 2023). This aligns with global trends where governments aim to secure technological sovereignty, reduce dependence on foreign vendors, and establish resilient supply chains (ETSI, 2020). The Turkish Regulatory Authority (BTK) has announced requirements aimed at incentivizing domestic participation through strict local content, hardware, and software production criteria, reflecting a broader national policy objective (BTK, 2023).

This approach is motivated by multiple factors such as the need to enhance national security, foster innovation-driven economic growth, and increase participation in the emerging global supply chains of 5G infrastructure (OECD, 2021). Additionally, the increasing adoption of 5G technology on a global scale calls for a strategic framework that encourages domestic R&D, boosts employment in high-tech sectors, and ensures long-term technological sovereignty, particularly in critical areas such as IoT, autonomous systems, and smart city solutions (GSMA, 2020).

Balancing spectrum efficiency, fair competition, and local industrial development presents complex policy challenges. Effective spectrum utilization must incentivize innovation while maintaining market competitiveness and safeguarding national strategic interests. Besides, spectrum policies should extend beyond immediate fiscal gains, fostering an environment conducive to technological capability-building and industry competitiveness (Benkler et al., 2018).

As Türkiye heads towards for the 5G deployments, it faces both opportunities and challenges. Reducing local infrastructure complexities, fostering public-private investments, and ensuring regulatory coherence are critical for the successful

rollout of 5G services. By addressing these aspects, Türkiye aims to build a resilient and competitive 5G network, supporting its digital economy and aligning with international standards. The outcomes of this deployment will not only influence the future of Türkiye's telecom sector but also have broader implications for national economic and social development.

This paper explores how Türkiye's 5G deployment is set to influence the sector's growth trajectory, innovation capacity, and international positioning. It argues that the success of this deployment depends on carefully crafted policies that not only allocate spectrum efficiently but also catalyze local technological ecosystem development for improving digital productivity. Specifically, the work discusses potential policy instruments to optimize spectrum assignment, encourage domestic R&D, and attract foreign investments compatible with national sovereignty objectives (ETSI, 2020).

The commercial trajectory of 5G has increasingly drawn scholarly attention as deployment evidence accumulates globally. It has been seen that while 5G infrastructure investment generates positive spillover effects on GDP in early-adopter economies, the magnitude of these effects is highly heterogeneous across institutional contexts, with countries characterized by high financing costs and underdeveloped local vendor ecosystems consistently capturing lower returns (Sulemana et al, 2020). The 5G deployment outcomes will likely influence the country's digital infrastructure, impacting economic growth, national security, and regional competitiveness. Under the consideration of spectrum management's critical role for shaping Türkiye's long-term digital strategy, this research provides timely insights for policymakers, industry stakeholders, and academia aiming to foster a resilient, innovative, and globally competitive telecommunications sector.

This research is structured as follows. Section 2 provides a comprehensive overview of the telecommunications market in Türkiye, detailing historical network generations, current subscriber and revenue dynamics, market structure, and key infrastructure metrics to establish the context for the analysis. Section 3 delves into the historical background of spectrum auctions and planning in Türkiye, reviewing the processes and outcomes for 2G, 3G, 4.5G (LTE), and 5G auction, highlighting evolving regulatory approaches. Section 4 presents the core productivity analysis. It introduces the investment efficiency ratio (IER) methodology,

analyzes historical efficiency trends in relation to technological transitions and macroeconomic factors, and projects the financial viability of 5G investments under current conditions. Finally, Section 5 concludes the study by synthesizing the key findings, discussing their strategic implications, and proposing a targeted policy framework to bridge the identified 5G viability gap and support Türkiye's ambitions for technological sovereignty.

1. TELECOM MARKET OVERVIEW IN TÜRKİYE

Türkiye has an ecosystem that can closely adapt the developments in the mobile communication sector and immediately devote systems into practice. While 2G systems were first commercially tested in 1991 through the world, 2G began to be commercialized in Türkiye in 1994. However, it is seen that the gaps between the world and the commercialization times have increased with 3G. It is seen that 3G, which was commercialized in the early 2000s around the world, it was commercialized in Türkiye in 2009 (BTK,2024). Lag in 3G adoption compared to early-adopter economies suggests that while Türkiye demonstrates strong adaptive capacity in telecommunications, systemic barriers, including regulatory timing, spectrum allocation delays, and macroeconomic conditions, have historically constrained the pace of generational transitions. Understanding this pattern is essential for anticipating similar bottlenecks in the forthcoming 5G rollout.

Türkiye started using LTE technology on April 1, 2016, to meet the increasing capacity demand and coverage area needs. Hence LTE offers more data capacity, higher speed and lower latency compared to previous technologies. These services are provided in Türkiye by Turkcell, Türk Telekom and Vodafone, which are the local mobile network operators in Türkiye. As the next step through the evaluation of mobile communication, the 5G spectrum auction and deployment on the field are eagerly awaited by national and international stakeholders (BTK, 2024). The market consolidation of three dominant operators creates a concentrated but relatively stable investment environment. However, this structure also means that the financial health and strategic orientation of each operator will disproportionately determine the speed and geographic depth of 5G coverage.

Frequency bands of 5G operate across multiple frequency bands, including low sub-1 GHz, mid 1-6 GHz, and high mmWave 26-28 GHz frequencies. Low band provides wide coverage with throughput. However, mid-band balances

between coverage and throughput. Whereas high band offers ultra-fast speeds but limited coverage and penetration (Ausubel & Baranov, 2017). In Türkiye, in a parallel manner 5G auction covers spectrum in 700MHz low band and 3500 MHz mid band frequencies (AA, 2025). This two-band approach reflects a pragmatic deployment strategy while the 700 MHz band will enable cost-effective nationwide coverage and 3500 MHz band targets higher-capacity urban corridors. Notably, the exclusion of mmWave spectrum from the initial auction plan indicates that Türkiye is prioritizing broad accessibility over maximum throughput at this stage, which aligns with the coverage-first strategies observed in comparable middle-income economies.

Since Türkiye has close commercial ties and geographic proximity with Europe, the 5G deployment models for Türkiye should be projected from European instances. The European Commission announced its initial 5G Action Plan in 2016 including main concerns, and objectives to deploy 5G networks through EU member states (European Commissions, 2016). The EU 5G policy contains deployment of 5G in all populated zones by 2030 and implementing 5G corridors through member states that will expand network security, boost competition between vendors via avoiding dependance on any vendor and encouraging domestic 5G network equipment capabilities. The European Commission labeled three forerunner frequency bands for 5G utilization that the countries can regulate the same technical specifications and network vendors can manufacture systems that operate at the common frequencies bands which are low-band 700 MHz, mid-band 3.6 GHz [3.4 to 3.8 GHz], and high-band 26 GHz [24.25 to 27.5 GHz] (Lee et al., 2023). Türkiye's alignment with these harmonized frequency bands carries a strategic advantage beyond mere technical interoperability. It positions Turkish operators to procure equipment from a broader pool of international vendors operating at these standard frequencies, which can moderate capital expenditure and reduce supply chain concentration risks. Furthermore, the EU's emphasis on vendor diversification resonates with Türkiye's own stated ambitions for technological sovereignty in network infrastructure.

By the end of 2025's first half, a total of 96,487,051 mobile subscribers are available in Türkiye, including machine-to-machine (M2M) subscribers, corresponding to a penetration rate of approximately 112.6%. Excluding machine-to-machine (M2M) and the 0-9 age group, the mobile penetration rate is 115%. Türkiye has become the country that makes the most calls on mobile phones among

European countries as of 2025, with an average monthly mobile usage time of 473 minutes (BTK, 2025). This exceptional usage intensity, the highest in Europe by this metric, underscores the degree to which mobile connectivity has become embedded in daily economic and social activity in Türkiye. Such demand depth is a strong structural signal for operators. The user base is not only large but demonstrably active, which provides a commercially favorable foundation for monetizing the enhanced service tiers that 5G will enable. This high penetration implies that the Türkiye's mobile market is dynamic, however there is still a long way to go and open to innovation with new generation mobile services.

Although first generation of mobile systems are out of service, the remaining systems from 2G – 3G and LTE are still active across the country. The number of 3G subscribers decreased to 4,829,995 while the number of LTE subscribers is 89,513,414. The number of mobile broadband subscribers receiving internet service from mobile computers and mobile phones, together with 3G and LTE services is 76,633,414. The total amount of mobile internet usage is 3,986,733 TBytes and the number of M2M subscribers is 11.2 million (BTK, 2025). The overwhelming dominance of LTE, accounting for many active mobile broadband subscriptions, confirms that the existing infrastructure has reached a mature stage. This maturity is a double-edged dynamic for 5G: on one hand, it suggests that further productivity gains from LTE optimization are marginal, making the case for a new technological cycle more compelling; on the other hand, the continued presence of 3G highlights that legacy network maintenance costs will persist in parallel with 5G investment, placing additional pressure on operator capital allocation.

The number of prepaid mobile broadband subscribers is 13,320,517while the number of postpaid mobile broadband subscribers is 61,866,273. It is observed that 20.3% of mobile subscribers are prepaid subscribers, and the rate of postpaid subscribers has increased from 75.8% to 79.7% in the last year (BTK, 2025). This shows that the mobile network operators have constant income models based on the monthly subscriber payments. The sustained shift toward postpaid subscriptions is a noteworthy structural development. Postpaid models generate more predictable and recurring revenue streams for operators, which in turn can improve access to debt financing and reduce the perceived risk premium on long-term infrastructure investments. From a 5G investment readiness perspective, a market with a growing postpaid base provides operators with a more stable cash

flow profile against which large capital expenditures can be planned.

The mobile communication market is dominated by the 3 local network operators. Turkcell has a share of 40.1%, Vodafone has a share of 30.3%, and TT Mobil has a share of 29.6% in terms of subscriber numbers. When market shares are examined according to revenue as of the first half of 2025, it is seen that Turkcell's market share is 40.6%, Vodafone's market share is 35.1%, and TT Mobil's market share is 24.4%. According to revenue obtained from subscribers as of 2025, Turkcell's market share is 42.9%, while Vodafone and TT Mobil's market shares are 30.7% and 26.4%, respectively (BTK, 2025). This depicts that Turkcell's deployment strategy is the major driver for mobile vendors, and the market is driven by this policy. Besides, it suggests that Vodafone has been more successful in monetizing its subscriber base through premium-tier services.

Voice revenue constitutes 6.2% of TT Mobil's revenues, 8.7% of Vodafone's revenues, and 7% of Turkcell's revenues. SMS and MMS revenues create 23.6% of TT Mobil's revenues, 5.5% of Vodafone's revenues, and 2.2% of Turkcell's revenues. Data revenues form 67.4% of TT Mobil's, 85% of Vodafone's, and 89.7% of Turkcell's (BTK, 2025). This clearly indicates that data communication is the major source of revenue for MNOs, and they need to invest more in the data infrastructure.

In 2024, monthly revenue per subscriber is 299.7 ₺, for Turkcell, 284.6 ₺, for Vodafone, and 250.4 ₺for TT Mobil. As of 2022, mobile Average Revenue Per User (ARPU) was 15 € in Europe, as opposed to 42.5 € in the USA, 26.5 € in South Korea, and 25.9 € in Japan (BTK, 2025) (ETNO, 2024). Since 5G deployment is costly and needs initial investment, MNOs and vendors desire additional motivation to make this investment. Although consumer spending on telecom services and devices is under pressure due to financial effects from large-scale job losses and restricted disposable incomes, the critical nature of telecom services, both for general communication and as a tool for homeworking, private networks for manufacturing etc. is expected to offset such pressures. This should result in a steady, though reduced, increase in subscriber growth in many markets and motivate the MNOs to deploy 5G throughout the country.

The expansion of infrastructure will naturally occur due to increasing demand as the 5G is deployed in the field. Figure 1 shows the increment of fiber optic infrastructure length over time in Türkiye. By the end of first half 2025, fiber optic

infrastructure in Türkiye extends to 637.7 thousand km. As it's assumed that the current routine is maintained, it is expected that it will exceed 850 thousand km by the end of 2028. The continued growth of fiber backhaul infrastructure is not merely a complementary development while it is a prerequisite for the dense, low-latency performance that 5G promises, particularly for mid-band deployments. The projected trajectory suggests that the physical backbone capacity will be broadly sufficient to support initial 5G rollout phases. Nevertheless, the distribution of fiber density across urban and rural areas will ultimately determine how equitably 5G coverage and its associated productivity benefits are realized across different regions of Türkiye.

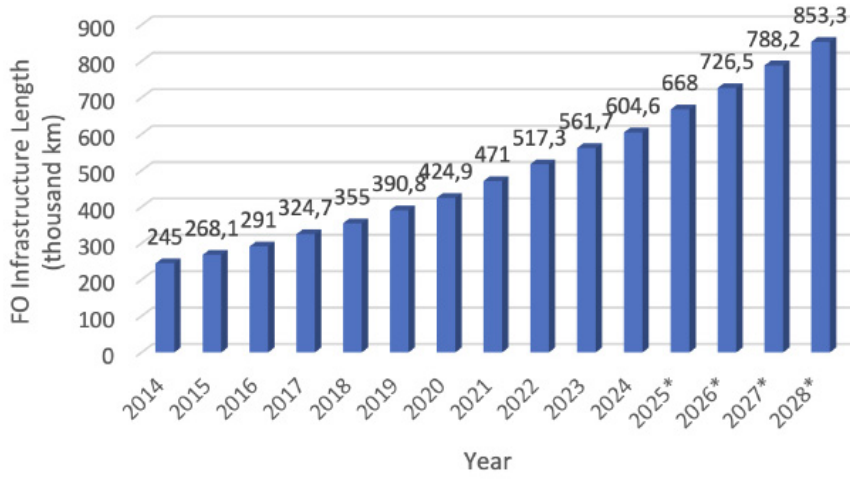
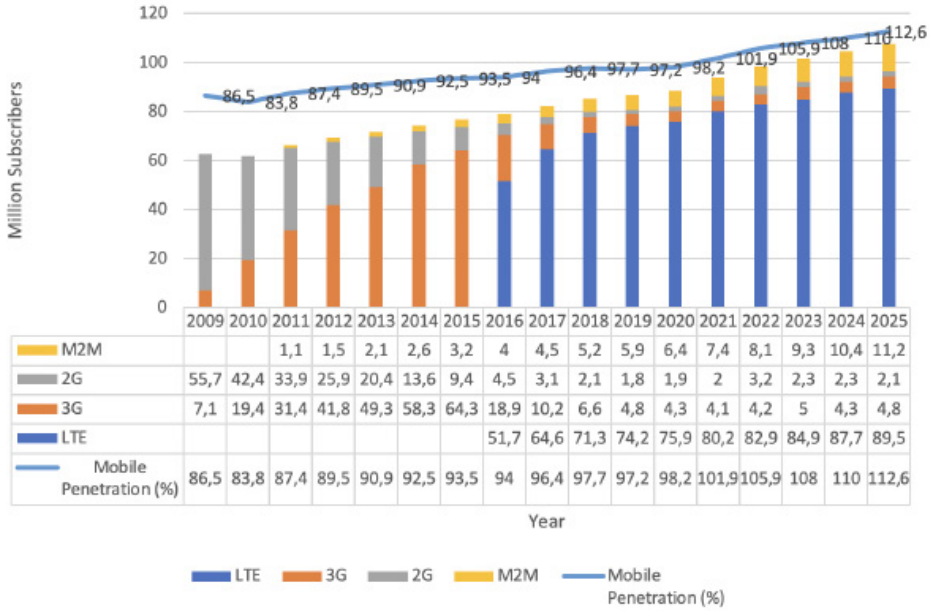


Figure 1. Fiber Optic Infrastructure Length in Türkiye
*Indicates the projection for the upcoming years

Figure 2 compares the number of 2G, 3G and 4.5G mobile subscribers and penetration rates by year. It can be seen from the figure that LTE is the major communication method for broadband and 2G is still active for three decades passed from its roll-out. In addition, machine-to-machine communication has the highest rate of annual increase in recent years. This yields the significance of IoT communication for the future projection and economic improvement based on the digitalization of economy.

Various factors such as economic status, education level, demographic structure, urban population, availability of ICT infrastructure, ICT cost, and institu-

tional environment variables can be mentioned as the key determinants for augmenting internet penetration rate. (Al Hammadany and Heshmati, 2011). The most vigorous findings of the econometric evaluations indicate that real GDP per capita and employment rate have a positive impact on internet diffusion. Moreover, the level of contents in local language and English proficiency among the population is a vital factor driving the internet penetration rate. Additionally, as the major driver advanced and continuously upgraded ICT infrastructure, accompanied by low ICT equipment/installation costs, is another propeller of mobile penetration. Finally, a regulatory framework advancing the local sector has also an encouraging effect on mobile penetration (Edquist, 2022).



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
M2M			1,1	1,5	2,1	2,6	3,2	4	4,5	5,2	5,9	6,4	7,4	8,1	9,3	10,4	11,2
2G	55,7	42,4	33,9	25,9	20,4	13,6	9,4	4,5	3,1	2,1	1,8	1,9	2	3,2	2,3	2,3	2,1
3G	7,1	19,4	31,4	41,8	49,3	58,3	64,3	18,9	10,2	6,6	4,8	4,3	4,1	4,2	5	4,3	4,8
LTE								51,7	64,6	71,3	74,2	75,9	80,2	82,9	84,9	87,7	89,5
Mobile Penetration (%)	86,5	83,8	87,4	89,5	90,9	92,5	93,5	94	96,4	97,7	97,2	98,2	101,9	105,9	108	110	112,6

Figure 2. Total Number of Mobile Subscribers and Penetration by Population in Türkiye

As seen in Figure 3, it is compared the mobile penetration rates of Türkiye and various European countries and the highest mobile penetration rates among European countries are Finland, Denmark, Germany, Austria and Italy. The average mobile penetration rate of the EU countries examined is approximately 133%. However, the mobile penetration rate is 112.6% and needs to be increased with the further deployment of 5G in Türkiye.

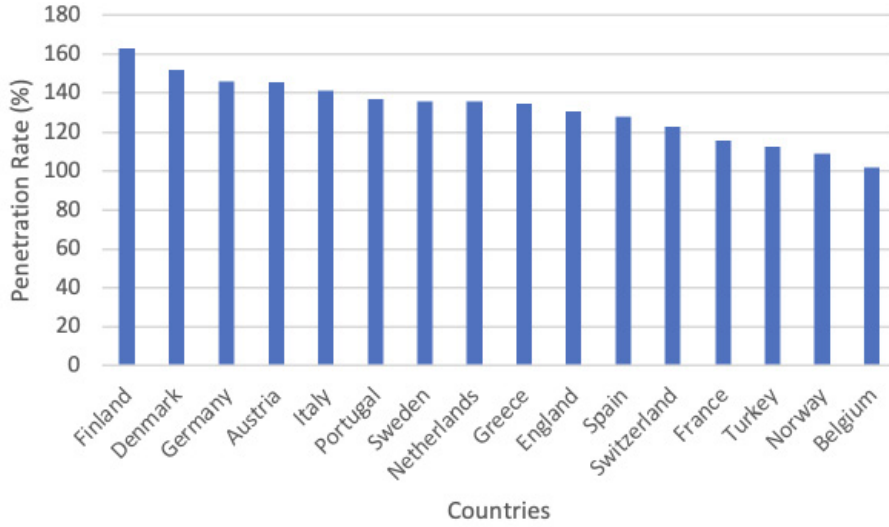


Figure 3. Penetration Rate Comparison of Türkiye with European Countries

Table 1 presents the annual net sales and capital investments of Türkiye's three licensed mobile network operators, TT Mobil, Turkcell, and Vodafone, denominated in Euros according to IFRS reporting standards, covering the period from 2014 to the first half of 2025. Several structural patterns warrant close attention. The year 2015 stands out as a singular inflection point while investment figures across all three operators surged dramatically, with TT Mobil recording a fivefold increase from its 2014 level and Turkcell nearly quintupling its annual investment. This synchronized investment spike directly reflects the LTE spectrum auction of September 2015, confirming that spectrum licensing events act as primary triggers for capital expenditure cycles in the Turkish telecom sector. Following this peak, investment levels normalized across 2016–2020, yet the revenue figures did not recover proportionally, partly reflecting the persistent depreciation of the Turkish Lira against the Euro. The 2025 data suggest a recovery trajectory in both sales and investment, likely anticipating 5G rollout. Notably, the persistent gap between Turkcell's revenue leadership and TT Mobil's lower investment-to-revenue ratio across the decade implies divergent capital efficiency strategies among operators.

Table 1. The Annual Net Sales and Investments of 3 Local MNOs in Türkiye

	Annual Net Sales (Million EUR)			Annual Investment (Million EUR)		
Year	TT Mobil	Turkcell	Vodafone	TT Mobil	Turkcell	Vodafone
2014	1,484.01	3,224.81	2,321.91	269.13	468.00	324.50
2015	1,645.54	3,333.19	2,792.11	1,362.39	2,243.77	1,276.70
2016	1,726.53	3,168.94	2,998.77	370.25	562.00	350.49
2017	1,615.39	2,959.92	2,664.93	239.88	503.72	239.23
2018	1,336.41	2,505.57	2,279.57	228.24	422.35	195.43
2019	1,408.22	2,544.77	2,176.13	262.79	775.81	202.48
2020	1,229.86	2,238.47	1,885.09	282.24	767.62	163.66
2021	1,095.25	1,991.89	1,703.74	236.32	553.23	182.52
2022	941.24	1,730.05	1,537.66	226.20	454.22	160.95
2023	1,163.89	2,117.84	1,909.32	275.28	661.09	235.04
2024	1,657.20	3,045.49	2,514.85	351.42	727.50	351.11
2025*	1,008.50	1,653.36	1,444.39	179.48	367.05	166.31

* Data for 2025 represents the first half of the year.

The annual investment/net sales ratio for the last 10 years is shown in Figure 4. The average investment ratios are %27 for Turk Telekom Mobile, %28 for Turkcell and %14 for Vodafone respectively. Besides the highest investment ratios belong to 2015 which is the year before LTE is actively get into operation in Türkiye. LTE auction is accomplished on 26.09.2015 and the service became available on 01.04.2016. Thus, local MNOs in Türkiye completed their investments and technical preparation in the year that LTE Auction is done.

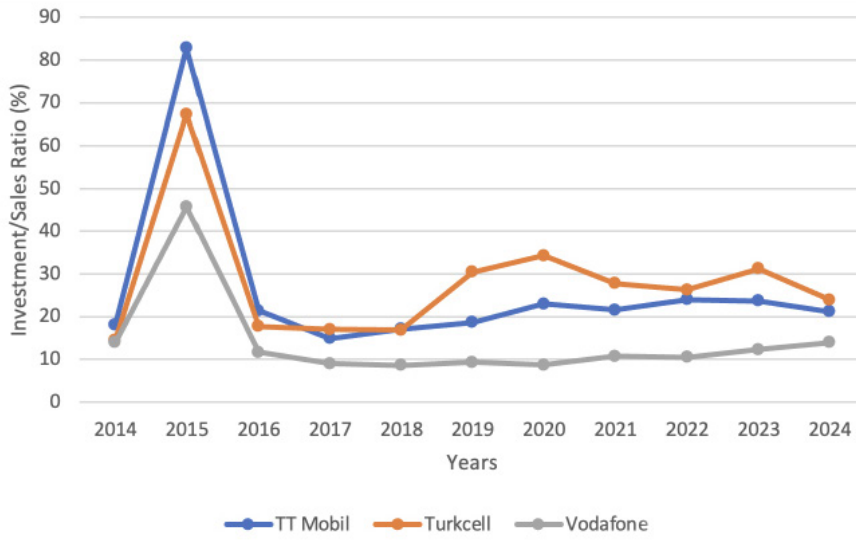


Figure 4. The Annual Investment/Net Sales Ratio for The Last 10 Years

One significant factor for infrastructure investment is considered as the interest rates, since the MNOs need financial resources for upgrading their systems. Figure 5 denotes the annual interest rates in Türkiye for the last 10 years. For telecom operators whose investment programs require multi-year capital commitments financed through debt lending rates at these levels transform investment calculus fundamentally. The annual financing cost of a €2.52 billion 5G spectrum commitment approaches €1 billion at 40% rates, nearly extinguishing the projected revenue uplift from 5G deployment.

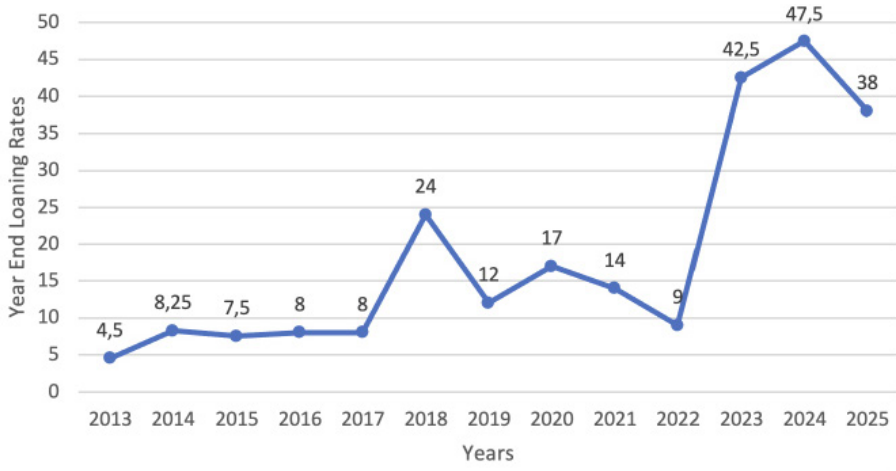


Figure 5. The Annual Loaning Rates for the Last 10 years in Türkiye

Significant local parameters those show the depth and progress of the ICT sector in Türkiye can be defined as the number of operators in the electronic communications sector and the number of authorizations these operators have. These numbers indicate the attractiveness of the sector and the success of regulatory institutions in providing market diversity. Figure 6 depicts the annual variation of ICT market players in Türkiye. The correlation between Figures 4 and 6 indicates the investment periods of the telecom sector are related to the frequency license auctions. For the 5G era, this pattern suggests that the 2025 spectrum auction is likely to stimulate a new wave of authorizations in segments such as private network operators, neutral host infrastructure providers, and edge computing service companies all of which are essential components of the industrial 5G ecosystem that Türkiye's policy framework aims to cultivate.

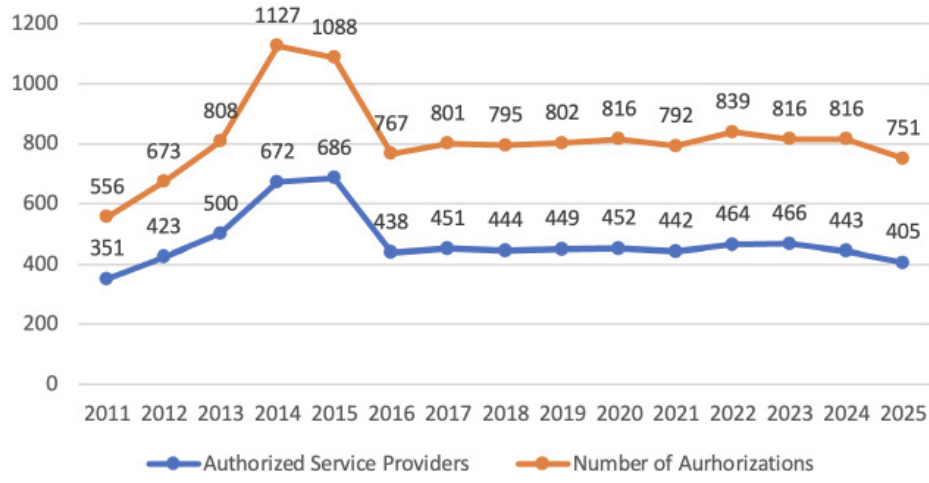


Figure 6. The number of operators in Türkiye's electronic communications sector and yearly authorization number

3. SPECTRUM AUCTIONS AND PLANNING IN BROADBAND SYSTEMS

5G spectrum auctions and the widespread adoption of ICT infrastructure serve as strategic instruments for structural transformation in national economies, extending beyond mere revenue generation to fostering long-term productivity and innovation (Georges, 2017). While proceeds from spectrum allocation can fund public infrastructure investments, the deployment of 5G networks significantly enhances operational efficiency, automation, and data-driven decision-making across various sectors from manufacturing and healthcare to smart agriculture and logistics. With its low latency, high connectivity capacity, and extensive IoT integration, 5G technology optimizes business processes, reduces operational costs, and enables new business models and digital services. This technological progress also promotes the upskilling of the workforce in digital competencies, revitalizes R&D ecosystems, and enhances technology-driven exports, thereby offering sustainable contributions to economic growth. Therefore, effective spectrum policy and widespread ICT infrastructure constitute fundamental determinants of a country's digital competitiveness and directly support macroeconomic productivity gains (Vu et al., 2020).

3.1. Historical Background in Türkiye

The development of mobile communication in Türkiye based on the GSM system commenced with the launch of Turkcell services in February 1994 couple years after the first GSM deployment in 1991. Subsequently Telsim, currently operating under Vodafone brand, began providing services. On April 27th, 1998, the Ministry of Transportation and Communications signed 25-year GSM license agreements with both Turkcell and Telsim, each for a consideration of $500 million. In 2004, another license, operating in the 1800 MHz band, was auctioned and awarded to a consortium brand name Aria, currently operating as Turk Telekom, and a third GSM operator was established in Türkiye.

Table 2. 3G License Auction Outcomes in Türkiye

Packet ID	Bandwidth (MHz)	Cost (Million Euro)	MNO
A	45	358	Turkcell
B	35	250	Vodafone
C	30	214	Turk Telekom
Total	**110**	**822**	

Table 2 summarizes the outcome of Türkiye's 3G licensing auction, conducted in 2008, which distributed 110 MHz of spectrum in the 2100 MHz band among the three incumbent operators at a combined cost of €822 million. The allocation followed a straightforward capacity-tiered structure, with Turkcell acquiring the largest bandwidth package (Type A, 45 MHz) at the highest price (€358 million), while Turk Telekom and Vodafone obtained progressively smaller allocations at lower cost. Several observations are notable. First, the total auction revenue of €822 million, while substantial for the period, stands considerably below the €3.36 billion generated by the 2015 LTE auction, reflecting both the lower strategic valuation of 3G spectrum at the time and the more limited competitive dynamics of a three-bidder market for pre-assigned package types. Second, the proportional bandwidth distribution while Turkcell receiving 41% of total spectrum, Vodafone 32%, and Turk Telekom 27%, established an asymmetric spectrum endowment that partially explains the divergence in subsequent network performance and subscriber growth trajectories.

Table 3. General Features of the 4.5G Frequency Auction in Türkiye

Packet ID	Frequency	Band-width (MHz)	Cost (Million Euro)	MNO
A1	800 MHz FDD	2x10	390	Vodafone
A2	800 MHz FDD	2x10	380	Turk Telekom
A3	800 MHz FDD	2x10	373.9	Turkcell
B1	900 MHz FDD	2x7.6	216.8	Turk Telekom
B2	900 MHz FDD	2x1.4	39.9	Vodafone
B3	900 MHz FDD	2x1.4	39.9	Turkcell
C1	1800 MHz FDD	2x29.8	430	Turkcell
C2	1800 MHz FDD	2x20	310	Turk Telekom
C3	1800 MHz FDD	2x10	95.1	Vodafone
D1	2100 MHZ FDD	2x5	160	Turkcell
D2	2100 MHZ FDD	2x5	188	Turkcell
D3	2100 MHZ FDD	1x10	35.66	Turkcell
E1	2600 MHz FDD	2x25	384	Turkcell
E2	2600 MHz FDD	2x15	240	Vodafone
E3	2600 MHz FDD	2x10	25.86	Turk Telekom
E4	2600 MHz FDD	2x10	Not Sold	Not Sold
F1	2600 MHz FDD	1x15	22	Turk Telekom
F2	2600 MHz FDD	1x10	12.9	Vodafone
F3	2600 MHz FDD	1x10	12.9	Turkcell
F4	2600 MHz FDD	1x5	Not Sold	Not Sold
Total		**390.4 MHz**	**3,357 €**	

In Table 3, general characteristic features of LTE frequency auction executed in 2015 are given. As compared with 2G and 2G, LTE frequency planning was more complicated and both FDD and TDD duplexing methods are activated simultaneously. Additionally, E4 and F4 packets are auctioned to promote the novel operators in Türkiye market. However, these frequency slots are stated unsold. E4 and F4 packages were dedicated frequency bands to encourage new telco players and more operators in Türkiye's mobile communications sector. However, the sector's heavy infrastructure investment requirements and the financial tightening experienced in Türkiye in the last decade do not allow for the emergence of new players. This situation will also be decisive in determining the payment methodology that current operators will prefer for frequency bands during the 5G auction process.

Although the first commercial LTE deployment among the world was in 2009, in Türkiye the 4.5G frequency licensing auction is enacted in 2015, and the first signal is transmitted in 2016. The main reasons for delays in nationwide 3G and 4.5G deployments compared to worldwide ones are expressed as the high investment costs, gradual return rates and lack of localization activities. As of mid-2025, the 5G auction timeline has not been released precisely and this can lead further delays on auction and roll-out of 5G in Türkiye.

Furthermore, due to the 20-year license agreements for 3G, awarded in 2009, and the 14-year agreements for 4.5G, awarded in 2015, these licenses are both set to expire around 2029. The fact that these licenses end in different years poses significant operational and regulatory challenges, thus the regulatory institute BTK organizes all licenses to end in 2029.

It is imperative to revise and harmonize the licensing agreements so that they conclude simultaneously. There is a considerable risk of service disruptions without such regulations, which could lead to a complete shutdown of 2G and 3G networks. Ensuring a coordinated and timely renewal of licenses is therefore vital for maintaining uninterrupted mobile communication services and safeguarding Türkiye's digital infrastructure in the coming years.

In Table 4, general characteristic features of 5G frequency auction executed in 2025 are given. As compared with LTE frequency planning, 5G bands are in 700 MHz and 3500MHz and both FDD and TDD duplexing methods are activated. Although 5G auction is completed in 2025, the initial signaling for 5G is planned for April 2026.

Table 4. General Features of the 5G Frequency Auction in Türkiye

Packet ID	Frequency	Band-width (MHz)	Cost (Million Euro)	MNO
A1	700 MHz FDD	2x10	366.67	Turkcell
A2	800 MHz FDD	2x10	364.10	Vodafone
A3	800 MHz FDD	2x10	363.25	Turk Telekom
B1	3500 MHz TDD	1x80	182.91	Turkcell
B2	3500 MHz TDD	1x80	178.63	Turk Telekom
B3	3500 MHz TDD	1x80	171.79	Vodafone
B4	3500 MHz TDD	1x20	159.83	Turkcell
B5	3500 MHz TDD	1x20	158.97	Turkcell
B6	3500 MHz TDD	1x20	177.78	Turkcell
B7	3500 MHz TDD	1x20	181.20	Turk Telekom
B8	3500 MHz TDD	1x20	211.97	Turk Telekom
Total		**400 MHz**	**2,517 €**	

3.2. Comparative Situation Analysis: Türkiye in the Global 5G Deployment Context

The global 5G deployment landscape offers a rich set of reference cases against which Türkiye's strategic positioning, deployment challenges, and realistic outcome expectations can be calibrated. As of mid-2025, the countries with the most mature 5G ecosystems can be listed as South Korea, the United States, China, Japan, and several EU member states. These countries have completed between four and seven years of commercial 5G operation, generating a substantial body of empirical evidence regarding deployment costs, revenue trajectories, and productivity effects.

South Korea launched commercial 5G services in April 2019 and has since achieved the world's highest 5G penetration rate, with approximately 30 million active 5G subscribers out of a population of 52 million by 2023 (Weissberger,

2023). The South Korean case is instructive for Türkiye primarily as a cautionary benchmark. Despite world-leading penetration rates, Korean operators such as SK Telecom, KT, and LG U+ have consistently reported that 5G revenues fell short of initial projections through 2023, largely because premium 5G-specific applications and services failed to materialize at the anticipated pace among mass-market consumers. Revenue recovery began only when operators pivoted toward B2B private network deployments in manufacturing and logistics sectors, aligning 5G monetization with industrial use cases rather than consumer broadband. This trajectory suggests that Türkiye should structure its 5G business case around industrial verticals and M2M applications from the outset, rather than assuming consumer revenue uplift alone will justify the investment.

China represents the largest-scale 5G deployment in absolute terms, with over 3.5 million base stations installed and more than 850 million 5G connections by end-2024, driven by a coordinated state-industry investment strategy that circumvents many of the financing cost challenges facing Turkish operators (GSMA, 2025). The Chinese deployment model, characterized by deep integration between state-owned operators, domestic equipment manufacturers and government financing mechanisms, reduced per-base-station deployment costs significantly below international benchmarks. While the state-ownership model is not directly replicable in Türkiye's market structure, the Chinese case provides strong empirical support for the combination of local content requirements, government-backed financing, and coordinated spectrum award mechanisms demonstrably accelerates deployment timelines and reduces per-unit capital costs.

Germany offers perhaps the most directly comparable European reference case for Türkiye's deployment context. Germany's 5G rollout, which began in commercial earnest following the 2019 spectrum auction, has been characterized by slower-than-projected coverage expansion particularly in rural areas due to high infrastructure sharing fragmentation, stringent permitting requirements, and financing constraints facing Deutsche Telekom, Vodafone Deutschland, and Telefónica Deutschland. By 2024, Germany had achieved 5G outdoor coverage for approximately 95% of the population in populated areas, but indoor penetration and rural corridor coverage remained substantially below EU targets (ETNO, 2024). The German experience directly resonates with Türkiye's structural challenge in which a three-operator market with differentiated investment strategies, significant rural-urban coverage disparities, and infrastructure dep-

loyment bottlenecks that are at least as much regulatory and logistical in nature as they are financial. The policy response in Germany including mandatory infrastructure sharing obligations, streamlined permitting procedures, and EU-funded coverage subsidies for uneconomic rural zones provides a practical template for the regulatory flexibility measures proposed in this study's policy framework.

Finland and Sweden, as the pioneering European 5G adopters, demonstrate what is achievable when financing conditions, regulatory frameworks, and vendor ecosystems are favorably aligned. Both countries achieved meaningful 5G commercial coverage within short time of their respective spectrum auctions, supported by long-standing relationships with domestic equipment, relatively low financing costs in the Eurozone environment, and mature wholesale infrastructure sharing markets that reduced duplication in passive infrastructure investment. Crucially, their ARPU levels where Finland's mobile ARPU of approximately €22–25 at 5G launch provided sufficient revenue per user to sustain the investment case even without immediate B2B uplift. The contrast with Türkiye's EUR-equivalent ARPU, estimated at €5–8 at current exchange rate, quantifies one of the most fundamental challenges facing Turkish operators. The revenue base per subscriber is structurally insufficient to support 5G deployment at European cost levels without explicit financial support mechanisms.

4. PRODUCTIVITY ANALYSIS AND STRATEGIC IMPLICATIONS OF 5G INVESTMENT

4.1. Investment Efficiency in Broadband Technologies

The investment efficiency ratio is a powerful metric to assess how effectively telecom operators convert infrastructure investments into revenue. This ratio is calculated for operator in year as:

$$\mathrm{IER}_{it} = \frac{\text{Annual Net Sales}_{it}}{\text{Annual Investment}_{it}} \tag{1}$$

In practical terms IER indicates how much an investment generates a return in annual revenue. The metric serves as a direct proxy for capital productivity in the telecom sector, where higher values signal more efficient use of investment

capital. To analyze trends over time and across operators, it's computed the sector-wide average IER:

$$\bar{\text{IER}}_t = \frac{1}{N}\sum_{i=1}^{N} \text{IER}_{it} \tag{2}$$

where represents Türkiye's three major Mobile Network Operators (MNOs). This aggregation helps identify industry-wide patterns rather than operator-specific fluctuations. The analysis incorporates Türkiye's annual lending rate () as a critical contextual variable. The relationship between investment efficiency and financing costs can be expressed as:

$$\text{IER}_t = f(r_t, \text{Tech}_t) \tag{3}$$

where represents the technological generation in operation. It is expected that when the it represents that a newer technology improves efficiency and when Higher interest rates reduce efficiency. Table 5 presents the calculated values alongside for the period 2014-2025. The dramatic variations in these values particularly the 2015 minimum () during peak 4.5G investment and the 2017 maximum () during post-deployment efficiency gains provide natural experiments to test these expected relationships. evolves in response to major sector events such as technological transitions and macroeconomic conditions such as interest rate changes. In this concept, two crucial parameters can be quantified the technology dividend, , which is the permanent efficiency gain from generational upgrades and the financial friction coefficient which is the sensitivity of efficiency to financing costs. These parameters derived become essential inputs for evaluating the financial viability of future 5G investments, forming the core of this productivity analysis.

Table 5. Annual Investment Efficiency Trends and Financial Context (2014-2025)

Year	Avg. IER	Lending Rate	Efficiency Change
2014	6.52	11.75%	—
2015	1.63	10.75%	-75%
2016	6.28	9.12%	285%
2017	7.92	9.25%	26%
2018	7.82	21.31%	-1%
2019	6.46	17.06%	-17%
2020	6.27	12.43%	-3%
2021	5.86	17.90%	-7%
2022	5.84	12.62%	-0.30%
2023	5.18	28.18%	-11%
2024	5.36	48.00%	3%
2025	6.27	~40.00%	17%

The analysis of investment efficiency from 2014 to 2025 reveals two dominant patterns that carry crucial implications for 5G deployment. First, generational network upgrades demonstrably enhance capital productivity. The transition to 4.5G serves as a compelling case study, following substantial investment in 2015 that temporarily depressed efficiency ratios, operators experienced a remarkable recovery. By 2017-2018, average efficiency peaked at approximately 7.9, representing a near-quadrupling from the investment trough and a sustained 25% improvement over the pre-4.5G baseline. This efficiency dividend emerged as enhanced network capabilities enabled higher-value data services, improved customer experience, and supported innovative tariff structures. The historical precedent shows us that the advanced mobile technologies, once deployed and adopted, create significant operational value by allowing operators to generate more revenue from their capital base. However, the second pattern reveals a formidable challenge that the macroeconomic conditions, particularly financing costs, exert

powerful downward pressure on investment efficiency. The data shows a strong inverse correlation between lending rates and efficiency metrics. As interest rates climbed from 2021 onward reaching extraordinary levels of 28-48% in 2023-2024, average efficiency ratios correspondingly declined, falling to approximately 5.2. This relationship quantifies a critical vulnerability that high-cost capital erodes the financial returns on infrastructure investment.

As the financial viability projection for 5G investments is examined by translating these historical insights to the upcoming 5G deployment allows for a pragmatic viability assessment. The total committed investment from the 2025 spectrum auction stands at approximately €2.52 billion. Based on the 4.5G precedent, a conservative estimate suggests 5G could generate additional annual revenues of €1.08 billion representing a 15% uplift from 2024 levels. Under foreseen financing conditions, this would imply a desirable payback period of 2-3 years, making the investment unequivocally sound. With lending rates hovering around 40%, the annual financing cost for the 5G investment approaches €1.01 billion. This reduces the net annual benefit to a marginal €70 million, extending the payback period beyond a decade and severely jeopardizing the investment's economic rationale. The stark contrast concerning technological potential and financial reality creates a 5G viability gap which is the difference between what technology can deliver and what current financing conditions allow to be captured.

Bridging this viability gap requires targeted interventions that address the identified constraints. A three-pronged policy approach is suggested to reduce risks generated by this gap. First, financial de-risking mechanisms can be generated to reduce the sensitivity to interest rates. Access to lower-cost capital can be facilitated specifically for 5G rollout covering local products and supporting localization in high-tech development. This could take the form of state-backed credit guarantees, dedicated low-interest loan facilities through development banks, or graduated spectrum fee schedules that align payments with revenue generation. The objective is to reduce the effective cost of capital for 5G infrastructure to below 15%, a threshold that would restore investment's financial attractiveness.

Second, accelerating local ecosystem development offers a parallel cost-reduction pathway. The emerging domestic capabilities in network equipment present an opportunity to reduce upfront capital expenditure. Especially in defence sector for the past decade, it has been proved that local content integration can lower

procurement costs dramatically while simultaneously creating technology development benefits such as university-industry collaboration, higher employment rates, lower import metrics and higher export potentials. Thus, regulation policy should link spectrum allocation incentives to commitments for local equipment procurement and joint R&D initiatives with Turkish technology firms.

Finally, operational flexibility must be enhanced by regulatory frameworks which can permit and encourage innovative deployment models, such as private and phased rollouts prioritizing industrial zones and metropolitan corridors where demand and ROI are highest, and infrastructure sharing arrangements that reduce duplicate investments. Additionally, reserving spectrum for private enterprise networks could create immediate revenue streams for operators while accelerating digital transformation in key economic sectors.

4.2. Strategic Gains from Türkiye's Transition to 5G

The financial viability analysis presented in the preceding sections establishes the investment challenge associated with Türkiye's 5G deployment. However, a comprehensive strategic assessment demands equal attention to the gains from economic, industrial, geopolitical, and social perspective that a successful 5G transition can generate. These gains extend well beyond the direct revenue improvements captured by the investment efficiency ratio and represent a broader rationale for public policy support that cannot be justified purely on the basis of operator-level financial returns.

4.2.1. Economic Productivity and GDP Contribution

The macroeconomic literature provides robust evidence that broadband infrastructure investments generate positive spillover effects on total factor productivity that exceed the direct returns captured by operators (Czernich et al., 2011; Bertschek et al., 2015). For 5G specifically, the productivity premium is theorized to be substantially larger than previous generations because of its combination of low latency, massive device connectivity, and network slicing capabilities that unlock entirely new production paradigms in manufacturing, agriculture, and services. GSMA (2020) projects that 5G will contribute approximately $2.2 trillion to global GDP by 2034, with emerging economies capturing a growing share as deployment matures. For Türkiye specifically, early modeling by the OECD

(2021) and sector-specific analyses suggest that full 5G penetration could add between 0.5% and 1.2% to annual GDP growth through productivity gains in manufacturing automation, smart logistics, and digital services that would accrue primarily to the broader economy rather than to telecom operators directly, providing the clearest justification for state co-investment in the deployment ecosystem.

4.2.2. Industrial Transformation and the Smart Manufacturing Dividend

Türkiye's manufacturing sector which accounts for approximately 22% of GDP and includes globally competitive positions in automotive, textiles, machinery, and electronics stands to gain disproportionately from 5G's private network capabilities. The deployment of campus networks in industrial zones, powered by 5G's ultra-reliable low-latency communications (URLLC), enables real-time process control, predictive maintenance, autonomous guided vehicles, and quality inspection systems that are not feasible over existing LTE or Wi-Fi infrastructure. Germany's automotive manufacturing experience provides a compelling reference where Volkswagen's deployment of private 5G networks in its Wolfsburg and Zwickau plants delivered a 30% reduction in unplanned downtime and a 15% improvement in production line efficiency within the first two years of operation. For Türkiye's Organized Industrial Zones (OIZ) of which there are 343 across the country, hosting over 60,000 manufacturing enterprises, 5G-enabled smart manufacturing represents a direct pathway to productivity improvements that can partially offset labor cost pressures and sustain the sector's international competitiveness.

4.2.3. Digital Services and the Platform Economy

5G's bandwidth and latency characteristics fundamentally alter the economics of digital content creation and delivery, augmented and virtual reality applications, cloud gaming, and telemedicine. Türkiye's large and young population with a median age of 32 and high smartphone penetration, constitutes a demographically favorable market for these next-generation digital services. The domestic digital economy, currently estimated at approximately 5.5% of GDP, has the potential to expand significantly under 5G conditions: mobile edge computing deployments enable latency-sensitive applications such as real-time language

translation, remote surgical assistance, and high-resolution video collaboration to function reliably over mobile networks for the first time. Each of these application categories represents not only direct consumer value but also potential export revenue if Turkish software and content companies can develop products optimized for 5G capabilities.

4.2.4. Technological Sovereignty and Domestic Industry Development

Perhaps the most strategically significant and most distinctively Turkish dimension of the 5G transition concerns the opportunity to develop domestic network equipment and software capabilities. BTK's local content requirements for the 5G auction (BTK, 2023) signal a deliberate policy intent to use spectrum allocation as an instrument of industrial policy, compelling operators to source a defined proportion of their network equipment from Turkish manufacturers. The defense sector precedent is instructive: Türkiye's investment in domestic defense industry capabilities over the past two decades covering radar systems, unmanned aerial vehicles, and communication equipment generated technology spillovers, skilled employment, and export revenues that substantially exceeded the initial public investment. A parallel trajectory in civilian telecommunications is both feasible and strategically valuable, particularly given the growing global market for 5G-compatible equipment as the developing world proceeds with its own rollouts. Companies such as ULAK, Aselsan, Havelsan, Argela, Netas and HTK have already demonstrated capability in network systems. A structured 5G domestic content program could catalyze their evolution toward full network equipment supply chains, reducing Türkiye's long-term dependence on foreign vendors for critical communications infrastructure.

4.2.5. National Security and Critical Infrastructure Resilience

5G networks will increasingly underpin critical infrastructure systems such as power grid management, water distribution automation, emergency response coordination, and financial transaction processing. The security architecture of these networks, including the choice of vendors, the design of network slicing configurations, and the governance of data sovereignty, therefore carries national security implications that extend beyond commercial telecommunications policy. Türkiye's decision to align its 5G frequency planning with EU standards while

simultaneously pursuing domestic equipment development reflects an awareness of this dual commercial-security dimension. The EU's experience with the 5G vendor security toolbox which classifies high-risk vendors and imposes restrictions on their participation in radio access networks provides a regulatory model that Türkiye can adapt to its own strategic context, ensuring that the security architecture of its 5G infrastructure supports rather than compromises national sovereignty objectives.

4.2.6. Closing the Digital Divide

Finally, 5G deployment offers a structural opportunity to narrow the persistent digital divide between metropolitan and rural Türkiye. The 700 MHz low-band spectrum acquired in the 2025 auction provides coverage economics favorable to rural deployment with cell radius potentially exceeding 10 kilometers under favorable propagation conditions, a relatively modest number of base stations can extend broadband coverage to communities currently underserved by fiber infrastructure. Fixed wireless access (FWA) services based on 5G low-band spectrum have demonstrated in countries such as the United States and New Zealand that rural households can receive broadband speeds exceeding 100 Mbps through 5G connections, at deployment costs substantially below those of fiber-to-the-premises programs. For Türkiye's approximately 20 million rural residents, many of whom currently rely on copper DSL connections with speeds below 20 Mbps, 5G FWA represents a technologically achievable and economically rational pathway to digital inclusion by enforcing coverage obligations effectively as conditions of the spectrum licenses awarded in 2025.

Taken together, these strategic dimensions establish that the case for Türkiye's 5G deployment is not contingent solely on the operator-level financial returns. The cumulative economic, industrial, security, and social gains from a successful transition constitute a public value proposition that justifies policy interventions designed to bridge the identified viability gap by transforming the financial challenge documented in this study from an obstacle into an opportunity for coordinated public-private investment in Türkiye's digital future.

5. CONCLUSIONS

This study has provided a comprehensive productivity analysis of Türkiye's mobile network transitions, with a specific focus on extracting evidence-based lessons for the imminent 5G deployment. By employing a longitudinal panel dataset of Turkish MNOs and calculating the investment efficiency ratio, the research has quantitatively unraveled the complex interplay between technological advancement, operator efficiency, and macroeconomic constraints.

The analysis yields two pivotal, yet divergent, insights. First, it robustly confirms the technology dividend inherent in generational upgrades. The transition to LTE, despite a significant initial investment outlay in 2015, led to a substantial and sustained improvement in operator capital productivity, with the average IER peaking nearly 30% above pre-deployment levels. This historical precedent strongly suggests that 5G holds analogous potential to enhance operational efficiency, enable innovative high-value services, and drive revenue growth for operators.

However, the second and more pressing finding reveals a critical vulnerability, the severe sensitivity of this productivity to financing costs. The strong inverse correlation between domestic lending rates and investment efficiency quantifies a formidable financial friction. The current macroeconomic landscape, characterized by high interest rates, fundamentally challenges the financial viability of 5G. The financing cost for the €2.52 billion spectrum acquisition can nearly nullify the projected annual revenue uplift under harsh economic conditions, extending the payback period to economically unfeasible lengths and creating a stark 5G viability gap.

Therefore, the success of Türkiye's 5G deployment and its ambition to achieve technological sovereignty cannot be left to market forces alone under existing financial constraints. Bridging this viability gap necessitates a proactive, holistic, and integrated policy framework that moves beyond spectrum allocation to actively shape the investment ecosystem. The findings advocate for a three-pronged strategic approach including financial de-risking mechanisms, accelerated local ecosystem development and enhanced operational and regulatory flexibility.

While this study establishes a quantitative framework for evaluating 5G investment efficiency under macroeconomic constraints, several dimensions re-

main open for future investigation. As post-deployment data becomes available following Türkiye's 2026 5G launch, the Investment Efficiency Ratio projections presented here can be empirically tested and refined against actual operator performance. Besides the impact of 5G digitization for industrial companies can be analyzed with field data as a future work.

In conclusion, Türkiye stands at a digital crossroads. While the technological promise of 5G is undeniable, its economic and strategic benefits are contingent upon overcoming significant financial headwinds. The lessons from the LTE era proved that technological transitions boost productivity, but their financial sustainability is fragile. A successful 5G deployment that serves as a catalyst for broad-based digital growth and technological sovereignty requires a concerted effort. It demands a synergistic policy mix that intelligently de-risks investment, vigorously promotes local innovation, and fosters a flexible market environment. By adopting such an integrated framework, Türkiye can transform the 5G challenge into a foundational opportunity, securing its position in the evolving global digital economy.

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