The Economics of the Fifth Generation Cellular Network

Abstract

Fifth generation (5G) networks make use of several technologies to enable ultrafast communication with low latency. Service providers can exploit new enterprise use cases and new sources of revenue. In spite of an initial high investment 5G networks are likely to have important positive economic and social effects. The paper advances our understanding of how 5G cellular networks are likely to have transformative impacts on national economies. Key technical details are presented in order to understand the costs and benefits associated with the development and deployment of 5G cellular networks. The paper gives special consideration to how 5G networks can play a role in addressing the potential bandwidth deficits at a low cost. The paper also analyzes the roles of economic linkages in the deployment and diffusion of 5G cellular networks. The paper argues that the most important benefits can be realized by combining 5G with other related technologies.

Keywords: *5G cellular networks; artificial intelligence; blockchain; economic linkages; Internet of Things; smart contracts.*

Introduction

Fifth generation (5G) cellular services were first deployed on a trial basis in the 2018 Winter Olympics in South Korea. Since then some telecommunications operators have commercially launched such services. In May 2018, Qatar's Ooredoo (formerly Qatar Telecom) reported that it launched what it referred to as the world's first 5G cellular services on a limited basis (Horwitz, 2018a). In June 2018, the Finnish telecommunications provider Elisa reported that it launched 5G networks in Tampere, Finland and Estonia's Tallinn. the company reported that it was already selling 5G service subscriptions. China's Huawei had provided the 5G terminal device (Horwitz, 2018b).

5G services are expected to rapidly take off in the next few years. According to Swedish networking and telecommunications company, Ericsson, 20% of mobile data traffic worldwide will be on 5G networks by 2023 (DeGrasse, 2018). The value-creating potential of 5G has significant implications for many industries. Many companies are developing products and services that would help enrich the global 5G ecosystem (Kshetri and Rojas, 2018).

An estimate by the cellphone trade group GSMA suggests that there will be 1.2 billion 5G connections worldwide by 2025 (Rakuten Today, 2018). 5G cellular networks are likely to diffuse rapidly in major economies. Asia and the U.S. are expected to take the lead in 5G, whereas Europe is reported to be lagging (Kharpal, 2018b). Among Asian economies, China is likely to experience the fastest 5G growth. A report released of the consultancy company EY indicated that China will have 576 million 5G users by 2025, which is more than 40% of the global total (Si, 2018b). Among European economies, the U.K. is likely to take a lead in 5G deployment (Rogerson, 2018). It is estimated that 90% of the U.K. population will be covered with 5G by 2027 (Oughton & Frias, 2018).

Just like other major technologies that were introduced in the past few decades such as cloud computing and big data, 5G services are likely to become a key source of firms' competitive advantages. 5G is expected to disrupt the mobile communication business ecosystem (Mattinmikko, 2018).

5G development and deployment can also strengthen national competitiveness. According to a leaked document, the U.S. National Security Council was reported to express concerns that China will win “politically, economically, and militarily" if the country dominates the telecommunications network industry" (Finley, 2018).

5G cellular networks have many attractive features, such as higher bandwidth, lower latency, and higher degree of reliability. Prior research conducted in the context of e-commerce demonstrates that 5G will create a rich e-commerce ecosystem and a better customer experience. In this way, 5G cellular networks on their own or in combination with other technologies are likely to have transformative economic impacts.

The development of 5G networks, platforms, and devices certainly require high investments. There are, however, important economic benefits associated with 5G networks. Despite the significance of this technology, there is a lack of research evaluating the broader economic impacts of 5G cellular networks.

The study intends to contribute to fill this research gap by investigating the potential economic impacts of 5G cellular networks and factors that may lead to successful deployment of this technology. Specifically, the objectives of this research are to: (1) to compare the key characteristics of 5G networks with lower generation networks, (2) evaluate the potential economic impacts of 5G networks, and (3) identify the roles of economic linkages in the diffusion of 5G networks.

The paper is structured as follows. We proceed by first examining the key characteristics of 5G networks. Next, we analyze potential impacts of 5G networks. Then, we look at the roles of economic linkages in the diffusion of 5G networks. It is followed by a section on discussion and implications. The final section provides concluding comments.

Key Characteristics of 5G Networks

In order to understand 5G networks' economic impacts, it is important to examine their key technological aspects. Like lower generation cellular networks, 5G networks use a system of cell sites, which divide a given territory into sectors. Encoded data is sent through radio waves. Each cell site is connected to a network backbone through wired or wireless connections (Segan, 2018).

Table 1 about here

5G networks also have important differences. Table 1 compares 5G with 4G on key characteristics and attributes.

Standards

There are two versions of the 5G standards. The non-standalone (NSA) is intended to be deployed on top of existing 4G/ Long-Term Evolution (LTE) infrastructures. The standalone (SA) version is for new installations (Hruska, 2018).

As to the question of which standards are appropriate for network providers, it is important to note that 5G networks are associated with high development and deployment costs (Alson & Shangkuan, 2017). Unsurprisingly, most wireless operators are planning to launch 5G with a heavy reliance on LTE. By doing so, they can use the same equipment and infrastructure to offer 5G services. For instance, early 5G adopters from Asia, such as South Korea's SK Telecom and Japan's NTT DoCoMo have shown preference for the NSA approach, which is less financially demanding. They would run integrated 4G/5G networks (Clark, 2018).

A GSMA Intelligence report suggested that SA deployment would perform better in terms of scale economies for a national rollout, but it needs more investment in the early stages (Clark, 2018). Telecommunications operators in China have announced plans to launch SA 5G, which is expected to coexist with LTE for some time. China Mobile announced its plan to deploy the SA version (Clark, 2018). China Unicom and China Telecom will also deploy SA 5G networks (Si, 2018a). The initial 5G offerings will target to users in dense urban areas that need increased speeds. For most personal use cases, there may not be a need for a 5G network. Indeed, a user may not be able to distinguish between enhanced 4G and 5G. Initial 5G networks will serve use cases that would require low latency or high throughput (Kenny, 2018).

Frequencies

5G networks will work from low to high frequencies. The high-frequency millimeter waves (MM waves) technology is expected to be deployed for ultra-high-bandwidth over short distances. On the other hand, long-haul data transmission will use lower frequencies (Hruksa, 2018).

In general, higher frequencies in 5G networks provide the most benefit over 4G (Segan, 2018). 5G networks thus mostly use higher frequencies for radio communications than used by lower generations (Table 1). Specifically the high-frequency MM waves utilize the band of spectrum between 30 gigahertz (Ghz) and 300 Ghz. Frequencies used by 5G arguably have characteristics that are more similar to light than radio waves (Margolis, 2018). They have a shorter range and can more easily pass through walls and buildings (Gartenberg, 2018a).

Compared to lower frequencies, higher frequencies, however, weaken more rapidly with distance. In order to prevent signals from being dropped, 5G networks use much smaller cell sizes compared to previous generations (Bleicher, 2012). Cell sizes in urban areas could be only a few hundred meters in diameter (Branch, 2018).

Tiny portable base station antennas are deployed that require minimal power to operate. In order to transmit MM waves, the antennas could be much smaller than traditional antennas. It is possible to stick them on a light pole or on the top of a building. They form a dense network and spread throughout cities (e.g., every 250 meters). They receive signals from other base stations and send data to users (Nordrum & Clark, 2017).

Speed

Compared to the frequency spectrum used by previous wireless network technologies, the amount of bandwidth available at MM wave frequencies is significantly higher (Browne, 2018). An obvious advantage of MM waves frequencies is thus that they provide the massive bandwidth required for massive data created by a large number of Internet of Things (IoT) devices and other sources.

In the 2018 Winter Olympics, South Korean telecommunications company Korea Telecom's peak 5G network speed was up to 3.5 gigabits per second (GBps) on Samsung tablets (Dano, 2018). It is worth noting that, in January 2018, South Korea's average mobile broadband download speed (which was the fourth highest in the world) was 133.05 megabits per second (Mbps). This means that peak speeds in 5G networks during the 2018 Winter Olympics were more than 26 times the country's mobile broadband download speed.

Most 4G base stations use twelve ports for antennas-- eight for transmitters and four for receivers-- to handle cellular traffic. 5G base stations can support about 100 ports (Nordrum & Clark, 2017). This means that a base station can send and receive signals from more users simultaneously. This phenomenon is referred to as massive multiple-input multiple-output (MIMO). Some estimates suggest that this is likely to increase the capacity of mobile networks at least by a factor of 22 (Nordrum, 2016).

5G networks provide more efficient use of spectrum. With a large number of stations, the frequencies that have been used in one station to serve a customer in that area can be reused by another station in a different area to connect other devices (Nordrum & Clark, 2017).

5G networks use traffic-signaling system known as beamforming, which identifies the most efficient data-delivery route to a given user. In doing so, it reduces interference for nearby users (Nordum & Clark, 2017).

Latency

4G LTE networks have relatively high latency, which varies between 30 mili seconds (MS) and 100 MS (Weiller, 2018) (Table 1). 5G networks get closer to the user in terms of antennas, which reduces the latency. This feature is especially valuable and useful for services such as remote robotic surgery and autonomous vehicles (AVs).

Devices connected to the network

5G networks were mainly used to connect cellular phones. 5G networks are used to connect a wide range of devices such as home appliances, industrial automation equipment, cars, laptops, and televisions) (Hruska, 2018).

5G networks support significantly larger numbers of devices per cell compared to previous generations. A working party developing 5G standards has specified at least one million devices per square kilometer (ITU, 2017).

Homogeneity/heterogeneity of services provided

In 5G, using software defined networking (SDN), a single network can provide a variety of heterogeneous services or 'slices' (Cave, 2018). In this way, network operators can provide specific capabilities for varying use cases (IDG, 2018). Indeed, it is argued that 5G networks are less about speed and more about capacity and the ability to provide targeted services for various use cases that are most in need (Fildes, 2018).

It is possible to optimize each slice in order to provide the required resources and quality of service (QoS) in terms of latency, data flow rate (throughput), capacity, and coverage (Dharmadbikari, 2018). 5G providers thus can address the difficulties with the one-size-fits-all nature of the 4G/LTE networks in which all customers are likely to receive the same types of services irrespective of the needs. For instance, 5G service providers can provide different types of networks with different levels of bandwidth, security, or latency for diverse applications such as smart homes, smart workplaces, or smart cities (Suriano, 2018).

Investments needed

Radio networks account for most of the investments in 5G. Small cell deployments and beamforming are likely to play a critical role in maximizing the performance of 5G networks. 5G services are thus likely to be more expensive than LTE (Hruksa, 2018).

According to technology advisory firm Xona Partners, in order to deliver a coverage comparable to existing 4G/LTE networks, 5G would need six times as much investment. The higher investment is needed because 5G networks improve performance by getting closer to the user in terms of antennas and computing power (Lyons & Rayal, 2018).

Korea Telecom's estimate based on its 5G trial during the 2018 Winter Olympics in Pyeongchang indicated that compared to 4G networks, 5G networks would require four times as many transmitters for a given area on average. 5G networks need to deploy extensive amount of fiber optic cables under city streets to connect concerned devices (Lyons & Rayal, 2018).

Cost per bit of data

Despite high initial investment, 5G networks enable a high data transfer rate. From an operator's standpoint, 5G networks have lower cost per bit of data compared to 4G networks (Bell, 2018).

In 5G networks, each slice can be managed independently. Network slicing can reduce operating expense (OPEX). Network slicing can promote flexibility, scalability and efficiency from the resource management perspective. Operators can analyze each slice's OPEX and revenue independently (Dharmadbikari, 2018). They can thus increase revenue and profitability.

Potential Impacts of 5G Networks

Prior research (Coppel, 2000) and anecdotal evidence suggest that ICTs and e-commerce have a powerful impact on national economies. A study conducted in 2000 suggested that B2B e-commerce would increase GDP by 5% in the long term in advanced economies (Brookes & Wahhaj, 2000). Among mature economies and large and developed countries, McKinsey Global

Institute's analysis of data for the period 2006-2010 indicated that the Internet accounted for 21% of the GDP growth during 2006-2010. It accounted for 3.4% of the GDP in 2009, which was more than communication, utilities, agriculture and mining (Manyika & Roxburgh, 2011).

Table 2 about here

The above benefits can be further improved with the adoption of 5G networks. Qualcomm predicted that by 2035, the 5G value chain will create as many as 22 million jobs worldwide and generate US$3.5 trillion in revenue worldwide (CTA, 2017). By that time, 5G's full economic benefit will amount US$12 trillion (Qualcomm, 2018). Table 2 presents the predicted economic impacts of 5G cellular networks in major economies.

A number of mechanisms can contribute to the ability of 5G to stimulate economic activities.

Prior research suggests that despite tremendous economic benefits, big data's use has not been as widespread as many had expected. According to a study conducted by IDC, only 0.5% of the world's information was analyzed in 2012 (emc.com, 2012). More recent studies have indicated that 5% of the created data has been utilized (Davis, 2017).

5G deployment is likely to result in a higher degree of utilization of created data. Estimates suggest that 5G will make it possible to utilize 35% of digital data (Davis, 2017).

For one things, it is not possible to transmit the data to a place where it can be processed and analyzed. The rate of data creation is growing more than two times as fast as the growth in bandwidth (Desai, 2017).

In order to understand the economic impacts of 5G networks, it would be useful to examine some of the industries likely to be transformed by this technology. We look at three key economic sectors: a) E-commerce, b) Autonomous vehicles, and c) Healthcare.

E-commerce

The faster speed of 5G networks and high-resolution screens of 5G-enabled devices might lead to a higher degree of customer willingness to engage in e-commerce activities, more time spent on e-commerce websites, and more purchases online. The features of 5G can also lead to a higher degree of effectiveness of e-commerce vendors' activities such as online advertising. Finally, faster speeds and higher-resolution screens are also associated with a higher degree of enjoyment (psychological or intangible benefits) when consumers engage in e-commerce activities.

Consider online video ads, which are a key component of an e-commerce ecosystem. In 2017, social video ad spending in the US was estimated at over US$4 billion dollars or 20% of the total social media ad sales (BI Intelligence, 2017). Most video ad tags contain sophisticated tracking codes, making it possible for advertisers to track users' interaction with the ads (Benes, 2018; Evans, 2009). Due to their larger file sizes, loading video ads is more difficult and time consuming than loading text or photos. This is a major concern because many viewers strongly dislike ads and other content that do not download quickly. In a survey conducted by Adobe in December 2017, about 80% of respondents said that if content takes too long to download, they will stop viewing it or switch to a different device. Likewise, another study conducted in 2017 by video analytics firm Mux found that 85% of respondents would stop watching a video if it takes too long to load (Benes, 2018).

5G offers great promise and potential to address these challenges. With 5G, data transmission and processing speeds will rocket to new levels. 5G will thus help create and deliver effective online video advertising that can attract customers' attention and produce the best results. Likewise, 5G networks ensure that devices do not lose Internet connections when traveling from one location to another.

Autonomous vehicles

Autonomous vehicles are capable of operating without human inputs in most conditions. In the U.S., autonomous vehicles (AVs) have the potential to reduce crashes by 90%, and save about US$190 billion annually (Bertoncello & Wee, 2015). AVs have already achieved impressive results. During the 2018 the 2018 Olympic Winter Games in PyeongChang, South Korea, AVs drove guests around the city's stadiums, ski slopes and ice rinks (Turak, 2018).

As noted above, high latency is a concern with the 4G LTE networks (Weiller, 2018) (Table 1). In order to maintain awareness of the surroundings and safely steer through traffic with vehicle-to-everything (V2X) communications, autonomous vehicles need a 1 MS latency (Browne, 2018). With 5G networks, an autonomous car will be able to hit the brakes and stop it within one inch compared to 4.6 feet taken with 4G (CTA, 2017).

Healthcare

Using 5G it is possible to perform remote robotic surgery in a more reliable and secure manner (Newman, 2018). From an operating room, a surgeon can watch a live feed and control a robotic arm remotely to perform surgery. The task requires a high data transmission rate and a low latency (Hanich, 2018).

5G's key features noted above make it possible to achieve the same accuracy and effect as performing a surgery on a patient in front of the surgeon. 5G networks can make it possible to get hospital services at home (Margolis, 2018).

With 5G it is possible to monitor things continuously. One benefit is personalization of healthcare. The ability to continuously collect patient-specific data and analyze them quickly. By communicating the processed information and recommended actions, patients can manage conditions on their own. In this way, 5G networks have the potential to increase the effectiveness of preventative care substantially (Davis, 2017).

Combining 5G networks with other technologies

Prior research conducted in the context of e-commerce suggests that 5G networks' value creating potential can be maximized if this technology is combined with other technologies such as artificial intelligence (AI), Internet of Things (IoT), blockchain, augmented reality (AR), and virtual reality (VR). The analysis can be generalized to other economic activities. Table 3 highlights some examples and benefits of combining 5G with other technologies.

Table 3 about here

Internet of Things

Estimates suggest that companies would spend about US$5 trillion on the IoT during 2018-2022 (Newman, 2017). There were from 6.6 billion IoT devices in 2016, which is expected to increase to 22.5 billion in 2021, (Newman, 2017). A study found that 70% of retailers worldwide were ready to adopt the IoT to improve consumer experiences (Dave, 2017).

The IoT can produce transformative economic impacts. For instance, IoT makes it easy to track inventory in real time and manage it more effectively. By doing so, human errors can be reduced. IoT can also help minimize waste, control costs, and reduce shortage. For instance, temperature-monitoring sensors can be used to maintain optimal temperatures for perishable products and send alerts when certain conditions are met.

Unsurprisingly, e-commerce companies have made heavy investments in IoT. China-based e-retailer JD.com's 3-System Fridge has sensors on every shelf and an internal camera. It registers the time and date when items are stored inside. The data is fed to a smart screen on the fridge's front side, which sends an alert when an expiration date is near. It can also order the next grocery list from JD.com based on the fridge's contents (Lye, 2016).

Vast amounts of structures and unstructured data are created by IoT devices. As mentioned, the amount of data created is growing more than twice as fast as the available bandwidth (Desai, 2017). It is estimated that by 2020, a network capacity that is at least 1,000 times the level of 2016 will be needed (Waterman, 2016). The amount of communication that needs to be handled will also increase costs exponentially. The current 4G networks are not capable of handling this growth. Due to their higher data transmission and processing speeds, 5G networks will play a key role in processing and analyzing massive amount of data created with a large number of IoT devices.

Artificial intelligence and machine learning

Artificial intelligence (AI) entails simulating human intelligence by machines. The key processes involved in AI are learning (acquiring information and understanding the rules for using the acquired information), reasoning (applying the rules to reach conclusions), and self-correction (ADB, 2018).

Machine learning (ML) is a type of AI that helps increase accuracy of software applications in predicting outcomes without explicit programming. The basic idea behind ML is simple: algorithms receive input data and by using statistical analysis they predict output values within acceptable ranges. ML processes are similar to those involved in data (ADB, 2018). mining and predictive modelling, which also look for patterns in data in order to adjust program actions.

AI and ML can be applied in diverse settings, such as in the (near) real time personalization and delivery of ads related to customer purchases. AI-enabled devices are already playing important roles in helping consumers in e-commerce activities such as making buying decisions and tracking products. For instance, virtual assistants are transforming the way consumers purchase products online. Amazon's personal assistant Alexa, for example, has been integrated into Amazon products as well as those from other manufacturers. Customers can use Alexa to find information about local concerts through eBay's online ticket exchange company StubHub. In addition, they can arrange transportation to the event via Uber and order pre-event dinner from Domino's. The order status can be tracked in real time (Asling, 2018). Likewise, consumers can order flower arrangements with 1-800-Flowers.com through Alexa or Google assistant-enabled devices (Renfrow, 2018). AI-enabled devices have already started handling unstructured information. For instance, social media platforms use AI to enable facial recognition and photo tagging (Harbet, 2018).

5G will dramatically improve consumer experiences with AI-based devices. With 5G, AI-based devices can access additional structured and unstructured information quicker and understand the environment and context better. Overall, AI-powered services will be more reliable in a wide range of contexts and situations in which they operate.

AI and ML would also help 5G operators deliver enhanced services to customers. For instance, ML and AI can identify the bandwidth requirements in a given situation. AI can translate a customer's intent and uses that insight to configure the network. Resources can be optimized based on workload models (IANS, 2018).

Finally, AI may improve cybersecurity in 5G. For instance, whenever some threats arise, machine learning can identify them using analytics (Rogers, 2018).

Virtual and augmented reality

In 2017, the retail industry was estimated to spend US$1 billion in VR/AR solutions, which was growing with a CAGR of 240%. By 2020, the retail would be the top industry for VR/AR spending. By 2025, the VR and AR retail markets are expected to reach US$1.6 billion and US$30 billion respectively (VR/AR Association, 2018).

VR and AR are likely to emerge as driving forces in diverse economic activities. For instance, by wearing a VR headset, a shopper can instantly find herself in a company's virtual shop, where she can "walk" around to explore items exactly as she would in the real shop. For instance, if she wants to know more about a new piece of jewelry in the shop, she can focus her sight on that item and see the relevant information needed to make a purchasing decision. If she wants to buy it, she can make the payment or add it to her cart and look for additional items (CIO, 2018).

AR applies VR in the real world with live video imagery (Perdue, 2017). For example, a furniture vendor can develop an AR-enabled app that allows a customer to point the mobile camera to the place where she wants to keep the furniture. The app places a 3D model of the furniture as an overlay on the living room's live image. The shopper now has a clear visualization of how the furniture would fit in her living room. In addition, by rotating the camera, she can see where the new furniture fits best (CIO, 2018). This has already been done by some companies such as Lego and IKEA (forbes.com, 2017). Likewise, the home furnishings and decor company Wayfair launched its AR app WayfairView in 2016, which is available in Google Play.

In the current online environment, consumers face difficulty in estimating objective product quality (Dimoka et al., 2012). A high level of uncertainty associated with product attributes that consumers are unable to experience online may lead to a lower willingness to buy online (Kim & Ramayya, 2015). 5G networks in combination with AR/VR would allow consumers to have the same experience as visiting physical stores regarding the design, fit, feel, and texture of the product.

The complexity and richness of the AR and VR worlds require processing a large quantity of data. Current 4G networks suffer from some limitations such as those related to bandwidth, latency, and uniformity, especially when the data needs to be fed remotely. In this regard, 5G networks are likely to unlock the full potential of VR and AR technologies. 5G's significantly faster speeds and lower latency would help overcome these weaknesses (Mundy, 2018). As noted above 5G streams' transmission delay is about 1 MS, which is much shorter than human beings can notice.

Contents with higher resolution require bigger data capacity. With lower generation networks, there is often a time lag between a user's actions and updates in the screen (IANS, 2018). Many people experience discomfort due to this time lag. This discomfort can be virtually eliminated with 5G networks. 5G networks' almost zero delay in transmission is thus likely to enrich customers' experiences with AR and VR technologies.

According to TimeTrade research, 85% of consumers prefer shopping in physical stores. Many features of brick and mortar stores cannot be replaced by e-commerce (Bragg, 2018). However, AR and VR can create consumer experiences that are close enough to brick and mortar stores.

By combining AR/VR with AI, retailers can create customer experience that is significantly closer to real-world environments. With AI, for instance, customers can view a realistic human avatar walking in the room. The customer thus has information needed to make the purchasing decision (Layton, 2018). This may lead to a higher relative preference for shopping online.

Retailers can also use AR and VR in concept testing to measure consumers' responses and feedback before implementing their ideas. Such testing can provide retailers with insights into consumers' emotional connection with the products, which can result in consumer adoption and market impact (Tamang, 2018).

Blockchain

Put simply blockchain can be viewed as a decentralized ledger that maintains records of a transaction simultaneously on multiple computers. After a block of records is entered into the ledger, the information in the block is mathematically connected to other blocks. In this way, a chain of immutable records is formed (Yaga et al., 2018). Due to this mathematical relationship, the information in a block cannot be changed without changing all blocks in the chain. Any alteration of information in a block would create a discrepancy that is likely to be noticed immediately by others in the network. To make sure only authorized users have access to the information blockchain-based systems verify identities using cryptography-based digital signatures. Transactions are signed with the users' "private key," and "public keys" are created using complicated algorithms that make it possible to share the information. Blockchain-based ledgers thus do not require record-keepers to trust each other. In this way, the dangers associated with data being stored in a central location by a single owner do not apply to blockchain.

Sophisticated applications of blockchain have been developed to facilitate a number of economic activities such as e-commerce, and supply chain management. For instance, Chinese e-commerce company JD.com has implemented blockchain in its supply-chain management system and B2B e-commerce. In 2017, the system went live with beef manufacturer Kerchin as its first supply-chain partner. The company announced plans to have more than 10 brands of alcohol, food, tea, and pharmaceutical products on its blockchain (Xiao, 2017).

One of the most high-profile future uses of blockchain is likely to be smart contracts. Smart contracts are agreements that is automatically executed by a computer program. Put differently, such contracts execute themselves “automatically under the right circumstances” (The Economist, 2015). A smart contract can be executed either “above” the blockchain or “on” the blockchain. In the former, the software program runs outside the blockchain and feeds information to the blockchain. In the second case, the software program is coded into blocks (Farrell et al., 2016).

In many smart contracts, effective communication between the underlying IoT infrastructure to facilitate reliable and secure processing of IoT data is critical (Reyna et al., 2018). When blockchain and IoT are integrated into a smart contract framework, the concerned parties need to decide where interactions would take place. Three possibilities can be envisaged: (a) inside the IoT; (b) a design that involves IoT and blockchain; (c) through blockchain. Especially the first approach requires reliable IoT data and low latency in IoT interactions (Reyna et al., 2018). In the cases of (a) and (b), smart contracts are executed “above” the blockchain. For (c), they are executed “on” the blockchain.

In smart contracts that are executed “above” the blockchain, 5G can play a key role in feeding the information (for example, from IoT devices) more efficiently. Many business models are evolving that combine blockchain with the IoT. For instance, a house is rented on AirBNB, could unlock automatically when the payment clears. In the music industry, smart contracts can help artists make some extra money by renting their equipment. The rented equipment will automatically turn off if payments are not received (Guez, 2016).

Swiss Coffee Alliance (SCA) uses Ambrosus' sensor-to-blockchain technology to fight unethical distribution of profits in the global coffee supply chains. The participants include SCA's network of farmers, roasters, product developers, manufacturers and retailers (Ambrosus, 2018). It utilizes blockchain, high-tech sensors, and smart contracts to create immutable records of transactions in the food industry (Cag, 2017). Products are tracked with sensors to transmit real-time environmental and logistical data (Cavanagh, 2018).

To take another example, the provider of compliance and certification and laboratory testing services, Breau Veritas has developed a blockchain-based system to provide highly reliable information about product's history. The system relies on continual verification rather than samples provides. The goal is to resolve ethical dilemmas consumers face in their decision to buy sustainable products (Whitworth, 2018).   Relevant participants share records and validate transactions (Whitworth, 2018). By flashing a QR code in-store, Shoppers can see a product's history in order to make informed purchase decisions (Business Wire, 2018).

The above examples make it clear that a smart contract's success hinges on the availability of reliable data and continual verification. 5G networks make it possible to receive and transmit created data in a reliable manner. In this way, organizations can use blockchain to create a real value proposition for the consumer.

Cyberattacks have been a main concern for the growth of e-commerce. Such concerns are further heightened by the rapid growth of IoT networks, as IoT sensors carry sensitive information about their users. Securing these systems is thus important. Another key use of blockchain would be addressing security issues in 5G. Telecom companies can provide an eSIM (embedded SIM) or an app to a subscriber that creates a unique virtual identity that is encrypted and stored on a blockchain. Subscribers can use the unique IDs for automatic authentication on e-commerce websites. Blockchain also allows for secure P2P network solutions.

Privacy and security issues in relation to 5G networks' cost-benefit analysis

Nations can achieve competitiveness by utilizing 5G networks only if they can manage associated risks (ITU News, 2018). The extent to which 5G's value creation potential is to be realized is likely to depend upon how privacy and security issues are handled. These issues are critical because according to Juniper Research, the cost of data breaches would amount US$2.1 trillion globally by 2019 (juniperresearch.com, 2015). There are additional costs that are often overlooked in the above estimates such as damage and destruction of data, lost productivity, theft of intellectual property, personal and financial data, post-breach disruption of companies' businesses, forensic investigation, restoration of hacked data and systems, and reputational harm. Including those costs, Cybersecurity Ventures estimated that cybercrimes cost the world US$3 trillion in 2015, which will increase to US$6 trillion annually by 2021 (cybersecurityventures.com, 2017).

In a survey conducted by Ericsson, 79% of the respondents from industries stated that "concerns around data security and privacy" were a barrier to 5G adoption. Likewise, according to the company's 5G Readiness Survey 2017, network security ranked as the third most essential 5G feature for service providers that were preparing for 5G deployment (Ericsson, 2018).

The evidence so far has been mixed, with some aspects of 5G deployment leading to strengthened cybersecurity while other features increasing vulnerability. On the plus side, application providers are developing systems that provide end-to-end encryption of data. Device owners hold the keys for decrypting the data. This means that in case of vulnerability in a network, the data are likely to be safe (Browne, 2018). In 2018, about half of all Internet traffic was encrypted. This proportion is expected to increase (Rogers, 2018).

A number of concerns have been raised regarding 5G's security. First, if a SDN controller is compromised, the hacker may gain privileged access to devices that it controls (Kirk, 2018). The hacker can cause substantial damage to the devices connected to the 5G network.

Second, in order to lower costs and/or enhance performance, collected data are likely to be stored at the edge instead of being transported back to a more central location. Note that edge computing involves co-locating computing, storage, and networking functions closer to where the data is generated. Doing this time and power required to send data back and forth between devices and the cloud would reduce. It conserves bandwidth and reduces latency (Billings, 2018). The edge may not have the same level of security as the central location (Gemalto, 2018).

Third, network slicing would require new and dynamic network security for each slice (Cisco, 2018). This is likely to increase the costs to secure 5G networks.

Fourth, cybercriminals may take advantage of 5G networks' low-latency and high-bandwidth capabilities to increase the potential scale of a distributed denial of service (DDoS) attacks. IoT devices can be targeted by hackers to use as a botnet (Millman, 2018).

Fifth, unlike previous generations, 5G networks will support more specialized use cases such as e-health and connected cars. Security in these cases have bigger risks (Cisco, 2018).

Economic Linkages and the Diffusion of 5G Networks

5G industry and market are embedded in the broader economy and thus their development should not be viewed as a self-contained phenomenon with self-contained solutions. 5G's development thus depends on the availability of related platforms, devices, and applications. For instance, during the 2018 Olympics, Korea Telecom provided 5G networks, Samsung provided 5G tablets, and Intel provided 5G platforms (Ramirez, 2018).

Of special interest is thus the development of related and supporting industries (Porter 1990). Development and diffusion of 5G are tightly linked to the forward linkages (demand), backward linkages (supply) and horizontal or inter-sectoral linkages (Markusen & Venables 1999). Table 4 presents the roles of linkage mechanisms in the development of 5G networks.

Table 4 about here

Forward linkages

The strength of forward linkages between 5G networks and the rest of the economy plays an essential role in determining the development of the 5G industry. The demand of 5G services is likely to be higher in economies that focus on advanced use cases that require reliable, fast and low latency networks.

Autonomous vehicles industry can give rise to forward linkages for the 5G industry. In South Korea, Hyundai and Korea Telecom developed 5G-equipped autonomous buses. The buses' interior video screens showed live coverage of events in 5G. Hyundai's aim is to start selling self-driving vehicles by 2021. Hyundai is also expected to launch self-driving taxis or ride-hailing services by that time. Korea Telecom's self-driving bus was referred to as the "5G Bus". They operated in the town of Gangneung, where ice hockey and skating matches took place.

Backward linkages

The development of industries that supply various ingredients needed for 5G helps to foster stronger backward linkages. In the case of 5G, relatively low cost of labor and other inputs for developing infrastructure are an important source of backward linkage. In this regard, China has cost advantages that lower 5G infrastructure costs. Deloitte estimated that the equipment necessary to develop a wireless network capacity cost about 35% less in China than in the U.S. (Kharpal, 2018a). According to Deloitte, from 2015 until the mid-2018, China spent US$24 billion more than the U.S. in 5G technology. China built 350,000 new cell sites during this period compared to fewer than 30,000 in the U.S. (Kharpal, 2018a).

More importantly, 5G-related R&D activities can provide strong backward linkages. As of March 2018, China accounted for 32% of the world's 5G standard contribution. By then, it had submitted over 8,700 related documents to the 3GPP and led 40% of the 5G standardization research items in 3GPP (Gambardella, 2018).

Local handset and devices manufactures are likely to provide the most important backward linkages. China-based technology companies ZTE and Huawei announced that they would release 5G smartphones by early 2019 (Kshetri & Rojas, 2018). South Korean device maker Samsung released its 5G tablet in early 2018. Samsung's 5G-equipped tablets allowed viewers to switch among multiple cameras placed along the cross-country skiing route so they could track an athlete's real-time location on a 3D map of the entire skiing course (Kshetri & Rojas, 2018).

Horizontal or inter-sectoral linkages

An intersectoral linkage is said to exist between two economic sectors if events in one provide a stimulus to another. Higher benefits of 5G can be derived by combining 5G with other technologies such as big data and AI. For instance, network operators need to use advanced analytics, ML and AI in order to manage service quality and predict failures. They are also required use contextual insight to take real-time actions (Ostiguy, 2018).

Mobile operators have taken initiatives in this direction. China Mobile announced its plan to enhance 5G's operational efficiency with AI (Si, 2018b). China Unicom and Tencent have established a joint laboratory to focus on R&D efforts related to key technologies and business applications. they include edge computing, network slicing and high-accuracy positioning services (Si, 2018a). Likewise, China Unicom's laboratory with Baidu aims to integrate AI with 5G. The two companies have placed special emphasis on the internet of vehicles and big data (Si, 2018a).

Discussion and implications

The major objectives of this research have been to compare the key characteristics of 5G networks with lower generation networks, evaluate their economic impacts and identify the roles of economic linkages. The key features of 5G enable the transmission and processing of the massive amount of data generated by IoT devices and other sources. 5G networks are thus associated with significant economic impact.

Overall 5G networks are likely to produce substantial economic impacts. However, the impacts are likely to vary across economies. The above analysis provides insights regarding favorable and unfavorable conditions for the deployment of 5G. The primary factors that are likely to contribute to favorable economics of 5G networks include densely populated urban environments where there are opportunities to support for advanced use cases. Some examples of such cases include driverless cars and smart cities. 5G network deployment in rural areas would be limited by unfavorable economics. On the demand side, such areas attractive use cases for the deployment of such networks. On the supply side, a large number of small cells are required to build such networks, which may not be economically viable in the short run.

Linkages with other related economic sectors are essential in the full utilization of 5G networks. For instance, the linkages provide the critical foundation for greater use of 5G networks in China and South Korea. Advanced and sophisticated uses of 5G thus may not be possible in countries in which the related sectors such as those related to AI and ML are not well developed.

Managerial and public policy implications

This paper has important implications for practice and public policy. The pricing models used in lower generation networks may not be relevant to the context of 5G networks. Mobile operators need to adopt different pricing and billing models for different market segments taking into account customer needs, the value of IoT for customers and the operators' IoT investments. For example, a vineyard owner may want to use IoT sensors to monitor the effects of factors such as temperature, sunlight, humidity and soil quality on the quality and yield of the grapes. Most mobile operators' major revenue sources in the pre 5G era consisted of selling SIM cards and charging a monthly fee for mobile data usage. In the above example, the vineyard owner might be against the idea of paying on a monthly basis since the sensors used in the crop yield monitoring consume very little data. A more preferable model for the vineyard owner might be based on the additional benefits that the monitoring solutions can provide during the lifetime of the crops (Hanich, 2018).

Early evidence indicates that major sources of competitive advantage in key industries may change in the 5G era. As noted earlier, South Korea's Hyundai (an automobile company) and Korea Telecom (a telecommunications company) developed 5G-equipped autonomous buses. The ability to handle large amount of data may be a more critical factor in the AV industry than any other factors.

As mentioned, 5G's performance in terms of cybersecurity is needed to determine true costs and benefits. 5G network providers and other value chain partners thus need to take measures to strengthen cybersecurity.

Public policy measures can help to reduce the burden of high investment costs. To take an example, in April 2018, the Korean Ministry of Information announced that it would allow major telecom providers such as SK Telecom, Korea Telecom, LG U+ and SK Broadband to share the cost of building a 5G network. It was estimated to save US$1 billion in capital and operating expenditures over 10 years (Lyons & Rayal, 2018).

Measures are also needed to address inter-sectoral linkages and interdependencies. in order to realize the economic benefits associated with 5G, incentives need to be created to attract foreign firms in industries in which local firms lack competitiveness.

Future research implications

Before concluding, we suggest several potentially fruitful avenues for future research. First, at present, there is no widespread commercial application of 5G networks. A possible avenue of future research is to analyze cases of 5G deployment when such cases are available for study. The epistemological efficacy of case studies is justifiable when the research question focuses on reasons behind observed phenomena, when behavioral events are not controlled, and when the emphasis is on contemporary events (Yin, 1989).

As mentioned, 5G networks have a number of more attractive features compared to lower generation cellular networks. In this regard, a second area of future research might be to examine how relative preference of a given 5G feature (e.g., faster data transmission) over another feature (e.g., latency) varies across different customer segments.

In this study we analyzed the potential roles of forward, backward and horizontal linkage mechanisms in the deployment and diffusion of 5G networks. Future researchers could look at the relative importance of one linkage mechanism versus another in creating positive impacts to the local economy. More in-depth analysis of one or more of the linkage mechanisms discussed above might be also worthwhile target of study.

Concluding comments

From the perspective of data transmission, 5G networks perform significantly better than the previous generations both in terms of capacity as well as cost effectiveness. 5G is thus a key “missing link” in the utilization of relevant data in order to make informed decisions based on data. The diffusion of 5G cellular networks is likely to lead to major economic and social impacts. Specifically, 5G (in combination with the IoT, AI, VR, AR, blockchain and other technologies) is bound to transform many industries and fundamentally alter consumption patterns. For instance, blockchain's technical potential as a means of creating trust, transparency and accountability can be realized by using 5G networks to provide reliable data. In this way, 5G can help consumers and other participants make informed decisions based on data.

The benefits of 5G can be enhanced by giving more attention to the economics of linkage effects, including the processes by which 5G can be combined with other technologies to deliver higher value to the end users. Many small developing countries lack linkages as well as necessary resources and capabilities that are essential to respond to the needs of the 5G era. Full potential of this technology cannot be realized without developing capabilities in areas such as advanced analytics, AI and ML.

Table 1: A comparison of 5G and 4G/LTE networks on key characteristics and attributes

Dimension	5G	4G/LTE	Remarks
Standards	December 2017. NSA version of 5G New Radio (NR) (which would be built on top of existing legacy LTE networks) (Gartenberg, 2018b). June 2018: SA 5G NR specification signed off by the 3GPP.	March 2008: the radio sector of the International Telecommunication Union (ITU-R) set standards for LTE/4G connectivity (Nelson, 2015).	The first LTE (also often called 4G) network was launched in 2011 (ADB. 2018). The NSA version has the advantage of low initial investment.
Frequencies	Uses MM wave Higher frequencies provide the most benefit over 4G (Segan, 2018).	Use frequencies below 6 GHz (Fisher, 2018).	The MM wave region is usually considered to be the range of wavelengths from 10 millimeters to 1 millimeter (EHTW, 2017).
Speed	ITU: 10 Gbps (Morris, 2015)	ITU: 100 Mbps (mobile) and 1 Gbps (fixed) (ITU, 2018)	5G's peak speeds are expected at 20 Gbps.
Latency	1-2 MS (0.001 or 0.002 seconds) (Horwitz, 2018c)	Average 50 MS (0.05 seconds).	Low latency is key for many smart mobility solutions such as V2X.
Devices connected to a cellular network	Wide range of devices (e.g., home appliances, industrial automation equipment, cars, laptops, televisions).	Mainly cellular phones	A working party developing 5G standards has specified at least one million devices per square kilometer
Homogeneity/heterogeneity of services	Heterogeneous	Homogeneous	In 5G, SDN is used to provide a variety of services (slices) based on user needs.
Investments needed	Relatively high	Relatively low	5G networks may need six times as much investment to provide coverage that is comparable to existing 4G/LTE networks.
Cost per bit of data	Low	High	5G is more economical in cases involving heavy data use

Table 2: The predicted economic impacts of 5G cellular networks in major economies

Economy	Forecast year	Study conducted by	Economic impact
China	2025	The China Academy of Information and Communications Technology, the Ministry of Industry and Information Technology	5G market will account for US$167 billion (3.2% of GDP) (Chow, 2017).
India	2035	A committee on India's 5G road map	Cumulative economic impact US$ 1 trillion (PTI, 2018).
The U.K.	2030	King’s College London	US$226 billion (King’s College London, 2018).
The U.S.	2024	Accenture	Boost GDP by US$500 billion, create up to 3 million new jobs (Amine et al., 2017).
World	2035	Qualcomm	5G value chain will create 22 million jobs, generate US$3.5 trillion in revenue, full economic benefit: US$12 trillion (Qualcomm, 2018).

Table 3. Combining 5G with other technologies to enhance e-commerce

Technology	Examples of uses	Benefits of combining with 5G
IoT	• Improve consumer experiences, track inventory in real time, manage orders more effectively	• Will make it easier to transfer, process and analyze data created by IoT devices
AI and ML	• Order products online, track orders, and perform other e-commerce activities	• Will make it possible to access additional information quicker and understand the environment and context better
Blockchain	• Smart contracts can be used by online vendors to automate order fulfillment; supply-chain management; B2B e-commerce	• Will address security issues and feed *the* information (for example, from IoT devices) required for a smart contract more efficiently
AR and VR	• AR-enabled apps allow a potential customer to virtually place real products in a real setting to provide a clear visualization of the products' use.	• 5G networks have higher bandwidth, reduced latency, and a higher degree of uniformity to deal with the complex worlds and sophisticated inputs that require processing huge amounts of data. • Reduced discomfort

Table 4: The roles of linkage mechanisms in the development of 5G networks

Linkage mechanism	Explanation	Some examples
Forward linkages	The 5G services are used as "the raw material" of another industry. New industries or businesses are formed or existing industries are likely to grow faster with 5G deployment.	5G is likely to stimulate the growth of the AV industry (e.g., South Korea).
Backward linkages	***I***ndustries or businesses that support 5G by creating various forms of positive externalities.	Costs and availability of labor, equipment, and other factors affect the development of 5G networks (e.g., China).
Horizontal or inter-sectoral linkages	Interaction between interdependent firms in two or more economic sectors usually with long-term cooperative arrangements. Actions taken by 5G network providers in partnership with other sectors outside 5G.	The development of 5G networks facilitate and are facilitated by the development of related technological sectors such as those related to AI and blockchain.

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